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BIKINI SCIENTIFIC RESURVEY

REPORT OF THE TECHNICAL DIRECTOR

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TECHNICAL REPORT

BIKINI SCIENTIFIC RESURVEY

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CANCELLED

Report of
THE TECHNICAL DIRECTOR

Prepared for
The Project Officer
by the Technical Reports Section

Edited and Published by
Armed Forces Special Weapons Project
December 1947

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PART III

REPORT OF THE TECHNICAL DIRECTOR

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INTRODUCTION

Volume II of the Technical Report, BIKINI SCIENTIFIC RESURVEY is the Report to the Project Officer, (Captain C. L. Engleman), U.S.N. made by the Technical Director, (Commander E. S. Gilfillan, U.S.N.R.). It comprises Part III of the overall Technical Report, and includes the data and conclusions of the various Scientific Groups that worked in and about Bikini Atoll, at Rongerik Atoll, and at Kwajalein. The investigations of these Scientific Groups were supervised and coordinated by the Technical Director.

The general objectives and the personnel of the Scientific Groups which participated in the BIKINI SCIENTIFIC RESURVEY have been dealt with in Volume I (Section 1.007), and only a brief outline of these groups will be reproduced here, as follows:

A. Geology

1. Reef and Island Geology
2. Submarine Geology
3. Drilling Operations

B. Radiobiology

C. Fisheries

1. Reef and Lagoon Fishes
2. Pelagic Fishes
3. Population and Taxonomic Studies

D. Biology

1. Experimental Biology
2. Ecology and Morphology

E. Radiochemistry and Radiophysics

Several Military Groups, made up of Army and Navy personnel also participated in the scientific investigations, and their activities and findings, except those concerned with deep-diving operations, are included in this portion of the report because they are allied to the findings of the civilian scientists. These Military Groups (personnel and objectives in Volume I, Section 1.007) were as follows:

A. Radiological Safety
B. Radiological Health
C. Army Engineers
D. Aerology

It may be said that the work of the civilian and military scientists described in the following pages was concerned with two general goals: to discover what long-range effects, both physical and biological, might be in evidence subsequent to detonation of an atomic bomb; and to obtain as much scientific data as possible concerning the geological history and the present-day ecological relationships of Bikini Atoll, thus supplementing similar findings obtained at the time of Operation Crossroads.

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Such general objectives necessarily called for scientific studies conducted along divergent lines, but all contributing to one general picture, and one group of largely harmonious conclusions. Thus, some studies were geological from the academic standpoint, whereas others came within the scope of biology (botany and zoology), chemistry, and physics. Taken together, they made contribution to what might be termed the oceanography of the area, meanwhile providing certain conclusions that are partially or largely military in significance.

The laboratory facilities employed by Scientific and Military Groups, both on Chilton (APA-38) and on Bikini Island have been described in Section 2.006 of Volume I. Added details concerning their facilities, and the type of work in which they were utilized will be found in the group reports which follow. In interpreting these individual reports it must be kept in mind that some conclusions, and especially those concerned with relatively minor points, were almost certain to produce differences of opinion among the participating scientists. In part, this may be attributed to the fact that no two groups approached any given problem in exactly the same manner and with the same kind of data. Otherwise, failure to agree completely may be related to the fact that many inferences drawn were tentative, and admittedly subject to modification upon completion of continuing studies in the United States. An over all summary of activities, data, and conclusions has been prepared by the Technical Director, and is published as Annex IV to this report.

3.001 Island and Reef Geology of Bikini

The reef and island phase of geological studies was concerned with possible bomb effects upon reef-building organisms such as the corals and certain algae, and with the acquisition of all possible new information concerning the origin and geological history of reefs and atolls. This work was conducted by Dr. H. S. Ladd, assisted by Mr. J. I. Tracey, Dr. J. Harlan Johnson, Mr. G. G. Lill, and Dr. J. W. Wells.

A study of reef-forming organisms at Bikini had been made in the spring and summer of 1946, to determine their abundance, general condition, and normal rate of growth. A similar investigation was carried out in the course of the resurvey, by way of ascertaining whether these organisms exhibited any effects attributable to blast or radioactivity. A second type of data was derived from the study of cuttings and core samples which were made available by the drilling operations described in Section 3.003. These sub-surface samples were studied to determine their age, the conditions under which the various layers were deposited, and any alteration of materials subsequent to deposition. A third phase of the overall investigation was the study of living algae and corals in the area, to obtain background information used in interpreting the age and relationships of fossil algae and corals found in core samples.

A geological center was established on Bikini Island (see Section 2.006) soon after the resurvey began. Special equipment (aside from drilling operations) included shallow-water diving gear for obtaining submerged specimens of algae and corals, dredging gear for obtaining similar materials from the lagoon bottom, containers, and preserving fluids. Examinations of reef-building organisms were made on the lagoon and seaward sides of islands and reefs all the way around Bikini Lagoon. Similar studies also were conducted at Rongerik by Dr. Johnson and Dr. Wells to obtain an additional check upon possible bomb effects.

Final conclusions from the study of reef and island geology cannot be made until comprehensive study of cuttings and core samples have been completed by Mr. J. I. Tracey and paleontologists of the U.S. Geological Survey, and studies of corals and algae have been completed by Dr. Wells and Dr. Johnson. It is anticipated that a final report on academic phases of island and reef geology will be prepared, which, when properly cleared, may be published by the Geological Society of America, the U.S. Geological Survey of the Department of the Interior, or the Navy (if desired). In any event, this report will be available to the Chief of the Armed Forces Special Weapons Project.

During the spring and summer of 1946, specimens representing 44 genera and about 170 species of corals were collected in the Marshall Islands by scientists of the U.S. Geological Survey and others. Of these, 36 genera and about 135 species were found at Bikini Atoll, the area most intensively studied. Specimens were taken on the seaward and lagoon reefs, on coral heads, and in dredgings from the lagoon floor, and gave a good idea of the richness of the Bikini fauna.

The season of 1947 was devoted less to collection than to the study of ecologic distribution, but in the course of the work about 365 specimens were accumulated and shipped back to the United States for further study. These specimens included at least 15 species not previously collected at Bikini. Major

Figure 1. Dr. H. S. Ladd examines coral and algal growth fringing a reef pool. ABCR Photo No. 5019-8.

Figure 2. Geologists studying reef information around a pool out near the lithothamnion ridge. ABRC Photo No. 5019-5.

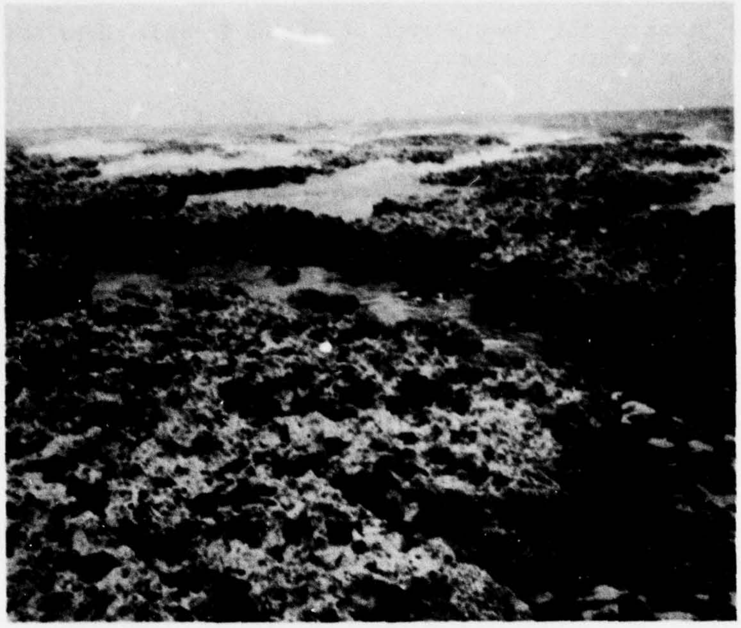

Figure 3. Close up view of the lithothamnion ridge between Enar and Rokar Islands, showing pits and cavities in the algal surface. ABCR Photo No. 5021-12.

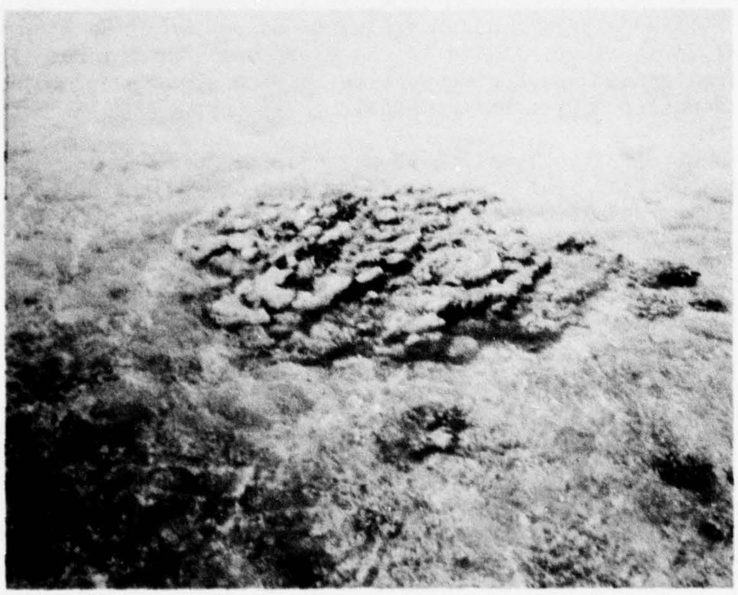

Figure 4. Porites growing on the reef flat of Bikini Island. ABCR Photo No. 5021-5.

attention was given to the seaward reef of Bikini Island. Here the following tentative zonation seemed to exist:

A. Lithothamnion ridge: zone of Acropora cuneata
B. Reef flat
   1. Behind lithothamnion ridge: zone of A. digitifera
   2. Area of coral patches (microatolls).
      (a) Mixed microatolls: zone of A. palifera a.
      (b) Heliopore microatolls: zone of Heliopora
      (c) Porites lutea microatolls (nearest shore): zone of Porites lutea

The foregoing zonation represents the complete development of a seaward reef on a windward island; individual zones are developed in varying degree in other situations, sometimes to a greater extent than on the "standard" site such as the magnificent Heliopora zone at the west end of Namu Islands. Several subzones, such as the surge channels and pools, may be added after study of their coral species.

Within Bikini Lagoon, a different situation exists, and tentative zonation is as follows:

A. Shoreward reef: zone of Heliopora and Porites andrewsi
B. Coral heads: zone of Acropora
C. Lagoon floor: zone of Acropora bikiniensis (name tentative)

Extremely important additions to knowledge of marine life outside Bikini Atoll were made as a result of dredging operations conducted by Dr. R. D. Russell on the seaward slopes down to a depth of about 800 ft. At least 20 new species of corals were obtained, providing an extension of data on the reed coral fauna downward to its lower limits in the "deep sea" coral zone. Further study of materials collected should give results bearing upon the problem as to the maximum depths attained by coral growths.

Traverses at specific localities, made during Operation Crossroads, both before Test A and after Test B, were re-examined during the Bikini resurvey. These traverses were laid out by pace and compass along an area 20 yd. wide, at the places indicated in figure 5. Detailed notes were made on the development and general condition of reef-dwelling organisms found. In addition, extensive areas along the reefs, from Bikini Island to Beacon Fox from Bikini Island to Enyu Island were studied in 1947. Results of this resurvey were as follows:

Traverses A, B, and C (Bikini Island)

On the reef flats no differences were noted; corals were abundant in places, and appeared to be healthy. The lithothamnion or algal ridge at the seaward margin, however, appeared quite different than it was in 1946. Calcareous algae and some of the corals on top of the ridge, exposed at low tide, were dull in color and covered with soft, brownish algae, in striking contrast with the bright pink and red algal development found the preceding year.

Traverse D (Beacon Fox)

The reef flat appeared unchanged. On the seaward margin of the reef, corals were brownish and generally poor in appearance, but calcareous algae were pink or whitened and not strikingly different than they had been in 1946.

Traverse E (northeast of Amen Island)

No changes were in evidence.

Traverse F (lagoon reef, Namu Island)

Corals on the reef flat appeared unchanged. Calcareous algae of the marginal zone were yellow to pink in color, and unhealthy in appearance. They were less colorful than they had been prior to Test A, and looked about as they did after Test B in 1946. Oil from target ships was in contact with this reef after Test B.

Traverses G and H (Oruk Island)

These were localities where oil from target ships drifted on to the reefs. Both seaward and channel reefs appeared to be in poorer condition than they were prior to Tests A and B. More soft, brown algae were present. Corals, however, appeared to be quite healthy.

Traverse I (Erik Island)

No changes were noted in this locality. Corals appeared to be very healthy, and algae were about as in 1946.

The poor condition of reef-building organisms noted above might be due to (a) radioactivity, (b) oil and/or sewage pollution, (c) seasonal changes in growing conditions, or (d) progressive changes in growing conditions. Of these possibilities radioactivity is considered to be the least likely cause, since the greatest changes were observed along the marginal zone of the seaward reef east of Bikini Island, a locality which has exhibited no radioactive contamination. It seems probable that the damage to reef-building organisms must be due to other causes which affected a number of the reefs, although it is admitted that these overlying causes may obscure possible changes due to radioactive contamination.

Pollution by oil and sewage would appear to be a major cause of damage to lagoon reefs and near-shore coral heads, but its selective importance in some situations is hard to establish. For example, it is difficult to explain how polluted lagoon waters could affect the windward reefs east of Bikini Island. Seasonal changes are known to occur, and it is probable that they have a marked effect upon the living conditions of reef-building organisms. However, the 1946 and 1947 surveys were made during the same season of the year. Very little is known about annual or progressive changes in oceanographic conditions, but such changes could, of course, be responsible for the effects noted.

The tentative general conclusion reached after field study of reef-building algae and corals, and after comparison of the situations found at Bikini and Rongerik, was that no evidence of damage noted in 1947 could be assigned definitely to blast or radiological effects.

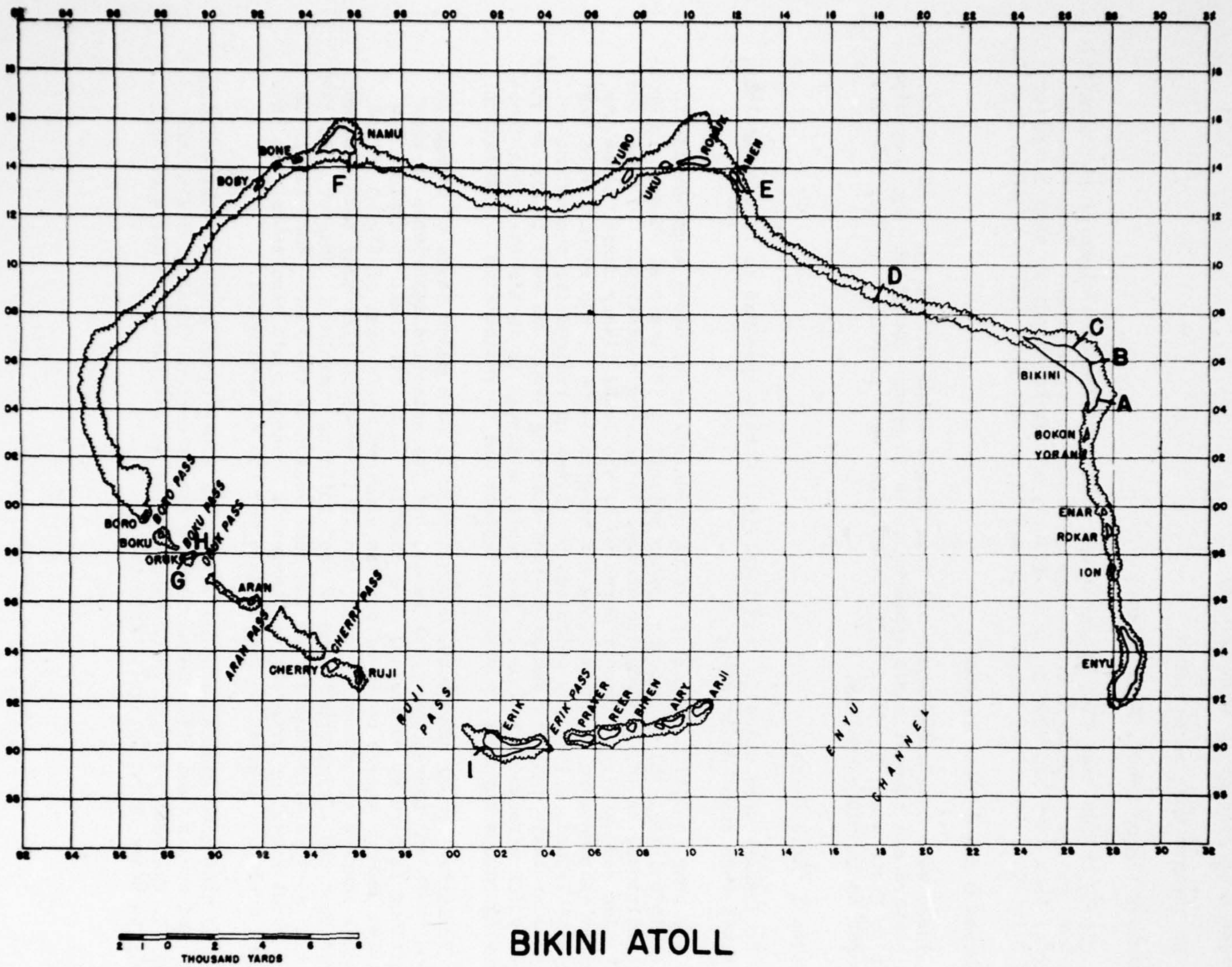

Figure 5. Traverses where reefs were studied by Geologists in 1946 and 1947, Bikini Atoll.

3.002 Submarine Geology of Bikini

The submarine geology studies conducted at Bikini Atoll in 1947 had a fourfold purpose, as follows:

A. To investigate, by means of sediment samples and cores of the bottom, the effects of the Test B explosion upon the lagoon floor, including the persistence and amount of radioactivity in the bottom sediments.

B. To obtain additional information concerning the geology of atolls, including their origin, by dredging on the outer slopes of the reef.

C. To supplement the data and check certain of the results obtained in the course of Operation Crossroads.

D. If possible, to obtain data on the origin of submarine banks by dredging and sampling on the 700-fathom bank northwest of Bikini Atoll.

These studies were directed by Dr. R. D. Russell, assisted by Mr. E. H. Shuler, and were carried on from the decks of the LCI(L)-615. Special gear included coring equipment, grab samplers, underway bottom samplers, heavy rock dredges, and underwater cameras. Special winches and accessory gear were installed on the LCI(L)-615 to handle this equipment.

In the course of the investigations, 33 cores of the lagoon floor, 240 bottom samples, 30 dredging hauls, and about 50 photographs of the bottom were obtained (see fig. 6 and fig. 7 for location of cores, bottom samples, and dredgings). In addition, about 450 lbs. of mud were taken from the site of Test B and forwarded to the Atomic Energy Commission for examination; and 250 gals. of water were collected 10 ft. below the surface and 10 ft. above the bottom at three locations for disposition by the Atomic Energy Commission. Three gallons of Halimeda debris also were collected from the lagoon floor for special tests.

Duplicate samples of all the cores were turned over to the Radiochemistry group for plutonium and fission-products analysis, and for the recording of alpha, beta, and gamma counts. The results of their studies are given in Section 3.017. Table VIII of that Section indicates the approximate location of each core relative of the Test B explosion point, and includes a brief description of the sediments penetrated.

Test B not only increased the depth of the lagoon bottom in the immediate vicinity of the explosion point (see fig. 27 of Enclosure F, "Report of the Coordinator of Oceanography", Crossroads Report), but also produced an area of mud which is quite distinct from any other sediment found in Bikini lagoon.

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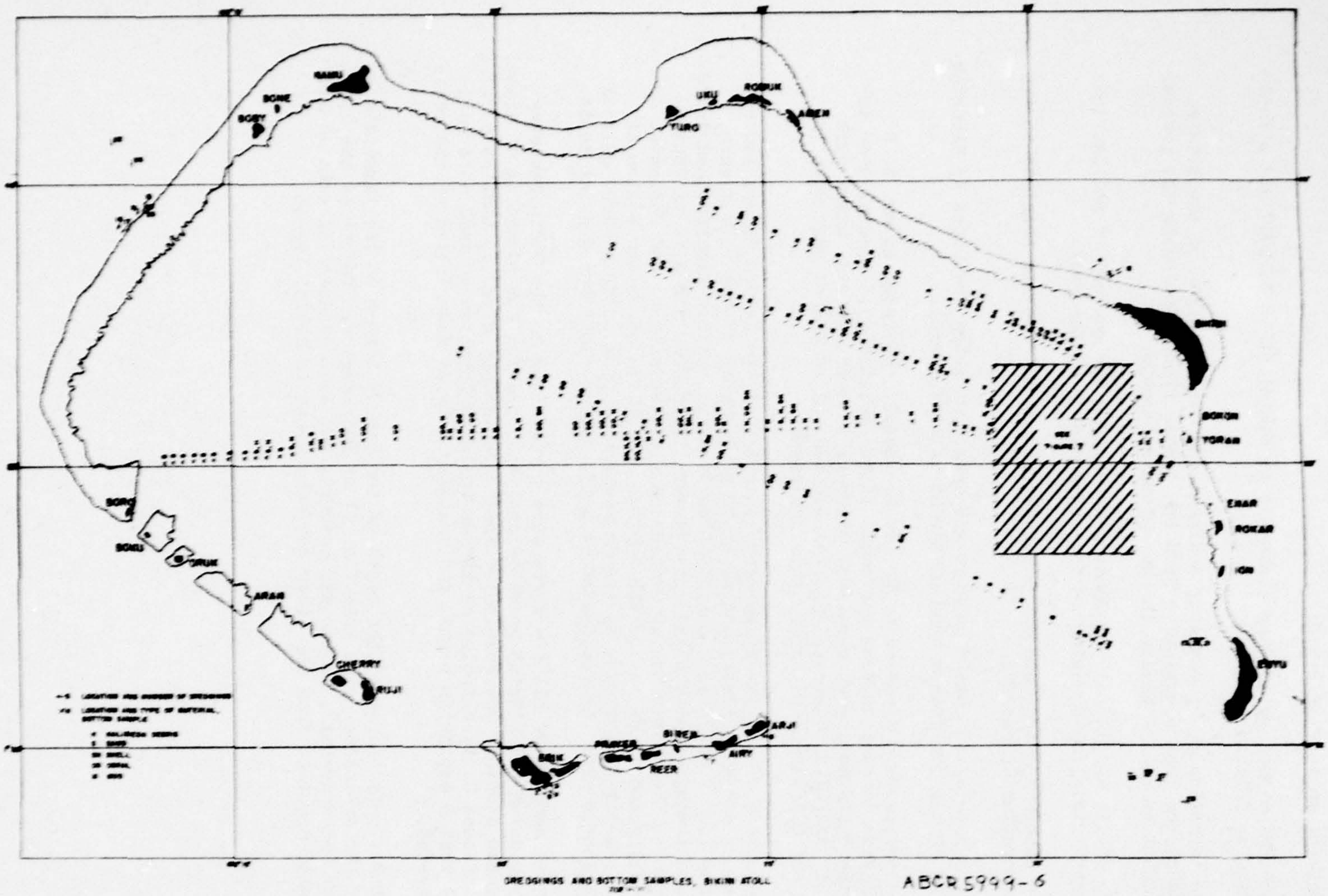

Figure 6. Dredging and bottom samples, Bikini Atoll. ABCR Photo No. 5999-6.

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Figure 8. Bottom photograph of "target area" mud. The black objects are sea cucumbers, which are numerous on the bottom in this area. N.E.L. Photo No. 1-1.

The characteristic sediment in the target area, prior to Test B, consisted chiefly of remains of the calcareous alga Halimeda. This alga, green when living consists of flat oval plates, 2mm.to 5mm. in diameter, joined together in series like a string of beads. When the plant dies, the green tissue decomposes and the plates fall apart, leaving a residue of small white or pale brown plates resembling uncooked rolled oats. With this Halimeda debris there usually is admixed a variable amount of mud (silt and clay-sized particles), sand, and shells.

Five cores taken in the vicinity of the explosion point two weeks after Test B in the summer of 1946 showed that this sediment no longer occurred in the target area. Instead, a layer of mud covered the bottom, with coarser material below. However, the 33 cores taken during the 1947 resurvey show that the typical sequence in the target area now is as follows:

A. A top layer of "target area" mud, grading through a thin transition zone into -

B. A layer of silt and fine to coarse silty sand, the coarseness increasing with depth. This in turn grades into -

C. A layer of clean, white Halimeda debris, with occasional fragments of green Halimeda. This rests, usually with a sharp contact, on -

D. Pale tan or brownish Halimeda debris with admixed mud and sand.

The bottom layer (D) of this sequence appears to be the original sediment of the target area prior to the Baker explosion. It usually is not radioactive. The three top layers (A,B,D) apparently represent material that was stirred up by the explosion and subsequently settled out roughly in a sequence based upon settling rates, though there is considerable mixing of sizes. Most of the Halimeda fragments settled first to form layer C, with some living green Halimeda included; the latter has not yet decomposed and still retaining its green color. Coarse sand, followed by progressively finer sand and silt-sized particles settled later, followed by the silt and clay-sized particles composing the mud. The latter is quite fine (about 40% of the particles by weight are less than two microns in diameter, and 35% between 20 and two microns), cream colored, and with a typical fetid odor. The mud contains the only evident non-calcareous material in the sediments -- dark streaks and occasional small, crumbly, dark-brown lumps which chemical tests indicate to be nearly pure carbon. The latter may represent the tissues of fish, or possibly oil, carbonized by the intense heat of the explosion. This carbonized material makes up less than 1% of the sediment. The mud also contains about 0.1% by weight of iron, presumably from the target ships.

Figure 8 shows the appearance of this mud bottom immediately below the former position of the LSM-60. Note that the mud is pitted by the borings of marine animals. Holothurians (sea cucumbers) are living on the bottom in abundance; three are shown in the photograph, which covers an area of approximately 16 ft. square.

The thickness of the three top layers of sediment in the target area varies greatly, as shown in figure 7* and in the cross-sections of figure 9*. In figure 9, the thicknesses of the various layers of sediment are plotted against distance from the position of LSM-60, with no attempt made to show the topography of the bottom. Two sections are shown; one running NE-SW, the other E-W. Note that the

* Figures 7 and 9 are included in Secret Supplement to this report.

layer is 5 ft. 3 in. thick below the LSM-60 location, and reaches a maximum of 8 ft. in thickness 125 yd. to the southwest in core No. 33. Also, the longest core taken (No. 4: 10 ft. in length) failed to penetrate the second layer (silt and sand) near the center of the target area. Near the edges of the mud area, on the other hand, the second and third layers frequently are missing (as in core No. 5), and a very thin layer of mud, a fraction of an inch in thickness, rests directly on the original bottom sediment (Halimeda debris).

Although the bottom was stirred up by the explosion to a distance of 1,000 to 1,500 yd. (fig. 9), the intense disturbance was limited to a radius of about 300 yd. Moreover, the center of intensity is about 100 yds. to 150 yds. southwest of the position of LSM-60. (The former position of LSM-60 was taken from figure 27 of Enclosure F, "Report of the Co-ordinator of Oceanography", Crossroads Report, and may be in error). Both figures 7 and 9 of the present report, and figure 27 of Enclosure F of the Crossroads Report, (which shows the increase in depth of water after Baker day) are comparable, however, and in essential agreement. The thickness of the mud layer (fig. 7 and fig. 9), of the other layers of disturbed and redeposited sediment (fig. 9), and the increase in depth of water as measured last summer, all show a symmetrical distribution, elongated to the southwest.

The radioactivity of the bottom material in the target area is concentrated in the top (mud) layer of re-deposited sediment. Though the second and third layers show some radioactivity, and even the superficial layer of normal sediment outside the mud area is weakly radioactive in many places, over 90% of the plutonium and fission products are in the mud (see Section 3.017). Therefore, an attempt has been made to estimate the volume and weight of this material. Owing to the difficulty in penetrating the coarse Halimeda debris with the coring instrument, and the restrictions imposed on the location of cores by sunken ships and by diving operations from COUGAL (ASR-8), the distribution and number of cores was not ideal for this purpose. With the additional information furnished by small bottom samples, however, a rough approximation is possible.

The dredgings obtained by the present expedition show that the outer part of reef is a typical talus slope, covered with large blocks of limestone broken off by waves from the edge of the reef. The size of these blocks apparently decreases with depth. Occasional rocks near the surface appear to weigh several tons, as a dredge attached by a one-inch chain to a half-inch cable was lost by breaking of the chain, after hooking on to a large block. Blocks weighing several hundred pounds are found down to more than 2,000 ft; a 5/32-in. stainless-steel airplane cable, carrying a small dredge, was broken when the dredge became caught at a depth of about 350 fathoms. The behavior of the dredges during the hauls, however, indicates that large blocks are rare below about 200 fathoms; the bottom being paved by masses of limestone with sand areas between.

Calcareous sand, consisting of remains of Halimeda, large foraminifera, shells, and ground-up coral and algal limestone, fills in the spaces between the blocks from the edge of the reef to depths of at least 600 fathoms. The amount of sand, relative to the larger fragments, increases with depth.

From 50 ft. (the shallowest dredging on the reef slope) to about 500 ft, living corals, algae, bryozoa, sponges, and other forms of marine life are present in abundance. The profusion and variety of life decreases rapidly with depth, however, and below 600 ft. the predominant forms are foraminifera, algae, a few deep-water corals, sponges, and brachiopods. Dredging No. 30, off Enyu Channel in 700 ft. of water, brought up a number of delicate branching corals, sea fans, sponges, and a starfish. This haul was in marked contrast to most of those taken at this depth, which characteristically consisted of rounded white cobbles, boulders, and blocks of limestone with little living material included.

The corals obtained in the dredgings were delivered to Dr. J. W. Wells of the Geology Group for identification and description. Many are new species, as little is known about deep-water corals. The calcareous algae will be described by Dr. J. H. Johnson. Other forms of marine life were turned over to the members of various scientific groups.

Figure 10. Scene aboard LCI(L)-615, as preparations are made to pick up a bottom sample. ABCR Photo No. 5061-1.

Figure 11. A conference concerned with drilling problems in session on Bikini Island. ABCR Photo No. 5041-1.

3.003 Drilling Operations at Bikini

Drilling operations conducted on Bikini Island contributed to all phases of geological and geophysical investigation, as indicated in Sections 3.001 and 3.002. The work was done under supervision of Mr. V.C. Mickle, and representatives of the G.E. Failing Co., as listed in Section 1.007.

A No. 1500 Failing portable drill rig was employed to drill holes on Bikini Island, at locations indicated in figure 12. Core samples and cuttings were taken at regular intervals of five to ten feet, labeled and packaged, and returned to the United States to become the basis for data used in final reports (see Sections 3.001 and 3.002).

As shown in figure 12, hole No. 1 was located on the seaward side of Bikini Island, just above the high tide level, and was drilled to a depth of 300 ft. Holes No. 2, No. 2A and No. 2B were in a similar location on the lagoon side of Bikini Island. Hole No. 2A was abandoned at a depth of 1,346 ft, and hole No. 2B was drilled to a depth of 2,556 ft. Hole No. 3 was located near the south end of Bikini Island, about 500 ft. from the seaward reef edge.

In addition to taking cores and cuttings to be used as a basis for more extended studies in the United States, some velocity tests were made as a check upon geophysical data obtained in 1946. These tests were conducted by Mr. J. P. Chernock of the Geotechnical Corporation, Dallas, Texas.

In general, with certain exceptions noted hereinafter, findings from the four holes drilled on Bikini Island suggested the following conclusions:

A. The top 75 feet consist of coral and algal rock and sand containing the remains of foraminifera and mollusks. This deposit is in part fairly well consolidated, but is extremely porous, full of minor cavities, and very difficult to core.

B. From approximately 75 ft. to 450 ft. the rock is a white, porous, very patchy limestone, full of minor cavities and sand. There is no apparent stratification. The cavities contained much secondary calcite, well-crystallized.

C. From approximately 450 ft. to 625 ft. was a transition zone of very soft, porous limestone. The rock at the top of this deposit was a light tan in color, which graded to brown at the base.

D. From approximately 625 ft. to 1,025 ft. the rock was a brown, soft, porous sand, with minor limestone patches. Some rich fossil zones occurred at from 900 ft. to 1,000 ft. Fossil corals, large and small mollusks and foraminifera were found, which were different from those living in the area today.

E. A consolidated, rotten, brown limestone was found at from 1,025 ft. to 1,050 ft.

F. At from 1,050 ft. to 2,556 ft. the rock consisted of loose, tan-to-brown, calcareous sand, very fine grained in part.

Cores were taken in Hole No. 1 from 0 ft. to 300 ft. In Holes No. 2 and 2A, cores were taken from 0 ft. to 500 ft, and at 50 ft. or 100 ft. intervals thereafter to 1,000 ft. Hole No. 2A was continued to 1,346 ft. by rock bit, and was abandoned when it was found impossible to set casing. Hole No. 2B was drilled to

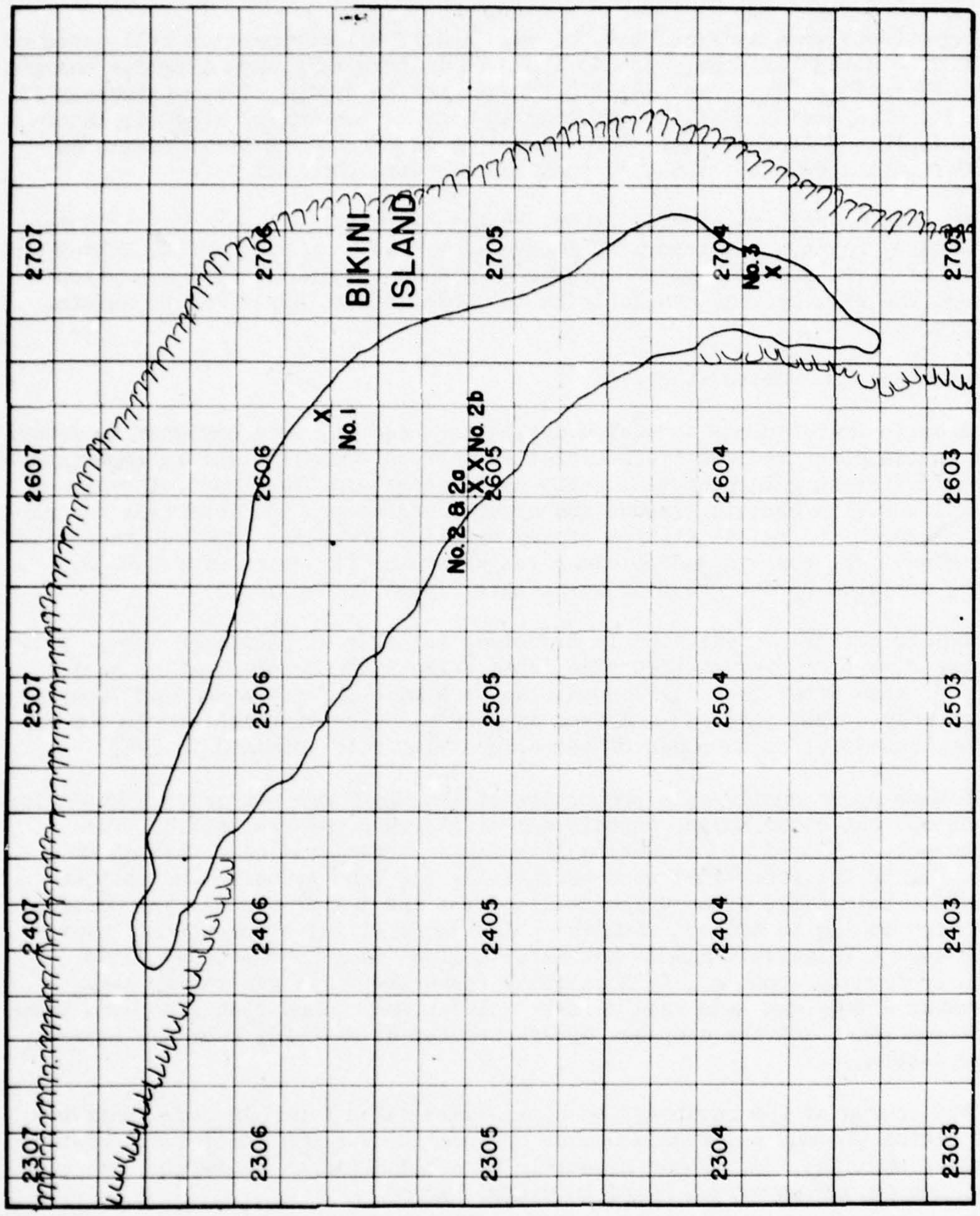

Figure 12. Location of drill holes on Bikini Island.

2,556 ft. by rock bit, and cutting samples were taken every 10 ft. Hole No. 4 was cored from 11 ft. to 117 ft, and was abandoned when mud circulation was lost. It is noteworthy that while Hole No. 3 was drilled approximately 500 ft. from the reef edge, corals were found in a position of growth at depths of from 60 ft. to 75 ft.

Seismic tests were made at Hole No. 2B. A Gulf Oil Corporation well detector was lowered to depths of from 50 ft. to 1,820 ft. in this hole, and dynamite charges were set off in Holes No. 2 and 2A, 178 ft. away and at depths of approximately 15 ft. to 35 ft. The position of the detector in Hole 2A was varied at 50 ft. intervals from depths of from 50 ft. to 800 ft, and at 100 ft. to 300 ft. intervals between 800 ft. and 1,820 ft. About 70 good records were obtained.

These records will be studied by Dr. Roland Beers of the Geotechnical Corporation, Dallas, Texas. His report will be used by the U. S. Geological Survey and the Office of Naval Research in re-interpreting data obtained during Operation Crossroads, and will be made available to the Chief of the Armed Forces Special Weapons Project.

3.004 Radiobiology Studies at Bikini

Studies in radiobiology conducted during the resurvey were designed to determine the incidence of radioactive material in various organisms and in organisms taken from different geographical locations; to ascertain the amount of radioactive substances in certain tissues and organs; and to collect materials for purposes of making histological studies of any existing anomalies upon return to the United States. The work in radiobiology was under the direction of Dr. L. R. Donaldson, assisted by the group of scientists listed in Section 1.007.

A similar survey of radiation in organisms was made at Bikini in 1946. Over 2,000 samples were counted at that time, some being taken before Test A, some after A, and some after Test B. Counts also were made on specimens from Rongelap (radiologically uncontaminated) and from Kwajalein. A substantial background was available, therefor, for purposes of comparison with data obtained in 1947.

Fish made up a considerable proportion of the specimens studied by the Radiobiology Group, but other marine animals and plants were not overlooked. The method commonly employed in collecting fish was to spread rotenone through an area of water in the intertidal zone-essentially the same procedure as that employed by the Scientific Group which studied reef and lagoon fishes (see Section 3.006). Fish coming in contact with the poison were killed or paralyzed, whereupon it became a relatively simple matter to collect them in dip nets, or to pick them up from the bottom. In localities where the water was fairly deep, shallow-water diving gear was used to make collections. Some fish also were taken with hook and line, and the deep-sea divers brought up material from the target fleet for testing.

In the course of the resurvey, specimens were taken from all representative areas of Bikini Lagoon, and from a number of localities along the seaward reefs (see Table I and fig. 13). Other materials were collected at Kwajalein, at Rongerik, and on sunken target ships in Bikini Lagoon.

Field identifications were made of all specimens, insofar as possible, and color photographs were taken of certain species for purposes of identification at a later date. In most cases complete specimens were performed in the field, and only certain organs or tissues were brought back for study. All specimens were placed in containers with preserving fluid, and returned to the Radiobiology Laboratory aboard <u>Chilton</u> (APA-38) (see Section 2.006).

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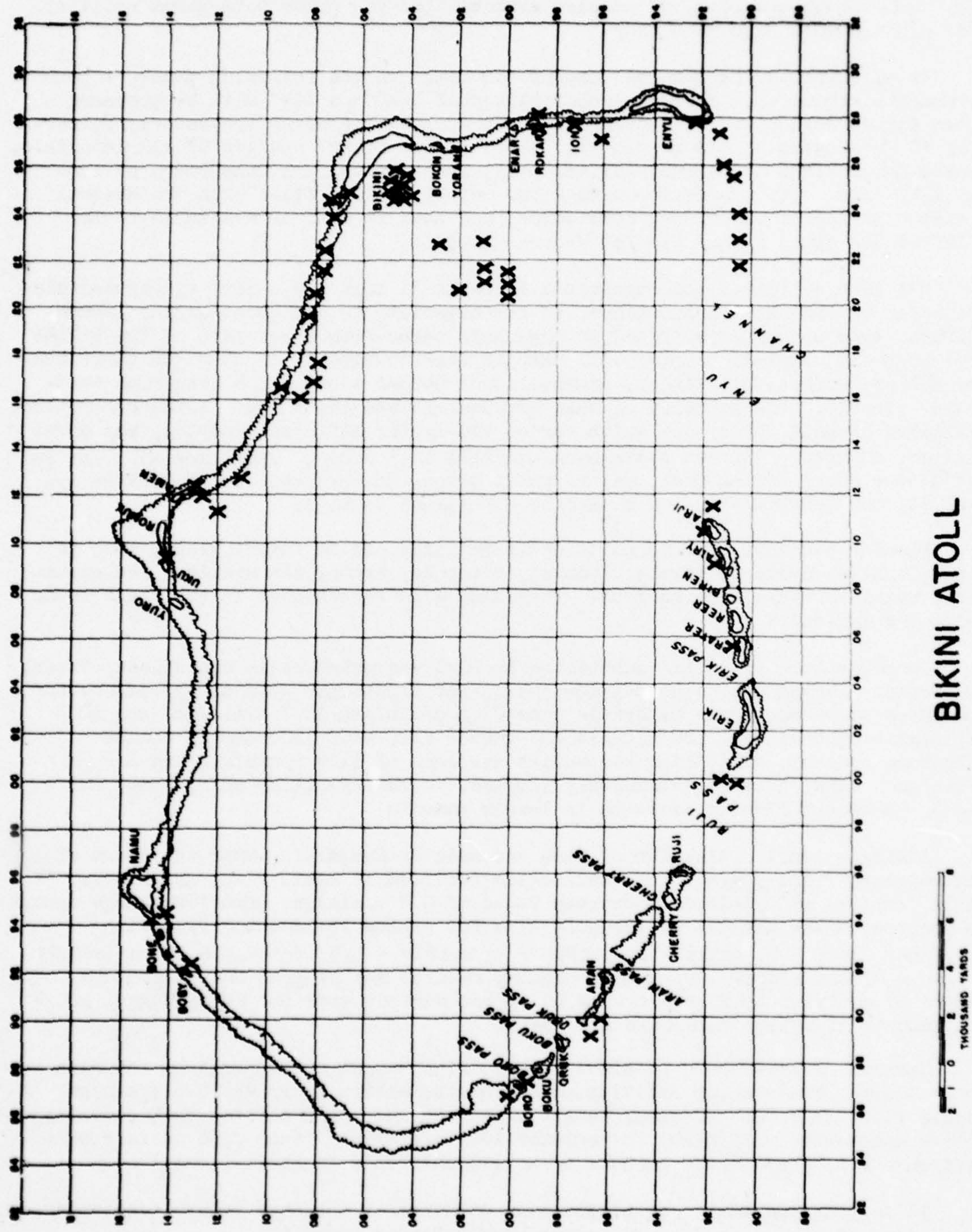

Figure 13. Distribution of stations at Bikini Atoll where collections were made by the Radiobiology Group during the Bikini resurvey of 1947.

[redacted]

In this laboratory, muffle-furnaces were available for the ashing of samples. Samples of convenient size (approximately 1 gm) were ashed, and then removed to the counter room, where 2,562 samples were counted for gross beta-gamma activity. Some alpha counts also were made.

In addition to the general conclusions cited in the following pages, a comprehensive report upon the research findings of 1946 and 1947 will be prepared under the direction of Dr. Donaldson at the Applied Fisheries Laboratory, University of Washington. This report will be based upon final studies of all materials, including sections of tissue, and also will incorporate full comparison of 1946 and 1947 data. It is understood that the report will be filed with the Medical Division of the Atomic Energy Commission, and that it will be available to the Chief of the Armed Forces Special Weapons Project.

The data collected and summarized in Table II indicate a very widespread distribution of radioactive substances in the organisms in and about Bikini Lagoon. In fact, some activity was found in organisms taken from every part of the Bikini area that was sampled. (Note: All samples were counted in an aluminum shelf sample holder, with a thin window, argon-alcohol Geiger tube, and a Tracerlab autoscalar circuit. The geometry of this arrangement was about 22%. Total absorption, exclusive of self absorption which varied widely for different samples, was about 6mg. cm. squared. Counter background averaged 18.5 c/min. Tabulated accounts refer to the above arrangement, and if total counts uncorrected for absorption are desired, the tabulated values should be multiplied by 4.5).

Fission products were found to occur in fish, and in invertebrates such as clams, snails, oysters, corals, sponges, octopods, crabs, sea urchins, sea cucumbers, spiny lobsters, and shrimps. They also were represented in the algae found about the lagoon.

Concentration of active substances in fish was greatest in the spleen, liver, and feces. Average gross beta-gamma counts per minute per gram of wet tissue for the three above mentioned materials were 23.5 c/min/gm, 18.7 c/min/gm, and 14.5 c/min/gm respectively. The kidneys and gonads were next in order of active-substance content, exhibiting respective averages of 11.6 c/min/gm, and 8.2 c/min/gm. Other tissues extensively sampled, including gills, skin, bone, and muscle contained fission products in lesser amounts.

A single small collection of fish was made at Kwajalein, near the stern of the capsized Prinz Eugen. This collection included 13 small fish, which were ashed (entire), and yielded an average value of 0.8 c/min/gm. Two fish large enough to produce tissue samples of adequate size for ashing yielded the following c/min/gm: bone - 0; gills - 0.6; skin - 2; muscle - 0.5; feces - 0; liver - 0.2; spleen - 2; and kidney - 0. The foregoing results may suggest that there are traces of activity in fishes living in direct contact with the Prinz Eugen, but the amounts of active materials are small.

Samples of liver were obtained from 35 fish caught at Rongerik by the Fisheries Group. The average activity count for the entire group was 0.6 c/min/gm. A single fish, an ocean skipjack, caught 14 August 1947, had a liver that contained active substances sufficient to register 10.5 c/min/gm. Other fish in this collection may have had trace amounts of active materials in their livers.

It is possible that some of the tuna at Rongerik obtained active substances by feeding at Bikini, before migrating to the former locality.

COLLECTIONS OF MARINE ORGANISMS FROM BIKINI, RONGERIK AND KWAJALEIN ATOLLS USED FOR THE STUDY OF RADIOACTIVITY OR PRESERVED FOR FUTURE STUDY

Date of Collection	Area	Specimens Counted	Specimens Preserved	Total	Remarks
7/15/47	Bikini Island	1	-	1	Hermit crab
16	2,504 (CHILTON)	2	2	4	Fishing off fantail
16	2,407 NW Bikini	15	154	169	Poisoning in 2 ft - 4 ft water in reef flat
16	Between Bikini and Amen	2	-	2	Trolling
17	Enyu Channel	2	-	2	Trolling
17	2,307 NW Bikini	22	132	154	Poisoning in 2 ft - 4 ft water in reef flat
18	1,709 Bikini-Amen Spit	27	224	251	Poisoning in 2 ft - 4 ft water in reef flat
18	2,504 (CHILTON)	-	1	1	Fishing off fantail
19	1,213 Amen	12	235	247	Poisoning in 2 ft - 4 ft water in reef flat
19	2,504 (CHILTON)	3	1	4	Fishing off fantail
21	1,213 Amen	3	-	3	Growth on metal pontoon dock
21	0,914 Uku	22	343	365	Poisoning in 2 ft - 4 ft water in reef flat
22	Enyu Channel	1	-	1	Trolling
22	2,504 (CHILTON)	3	1	4	Fishing off fantail
23	Enyu Channel	12	5	17	Trolling

Date of Collection	Area	Specimens Counted	Specimens Preserved	Total	Remarks
7/24/47	2,007 NW Bikini	14	174	188	Poisoning in 33 ft water around coral head
24	2,504 (CHILTON)	5	1	6	Fishing off fantail
25	Ruji Channel	7	4	11	Trolling
25	2,504 (CHILTON)	1	-	1	Fishing off fantail
26	Ruji Channel	11	1	12	Trolling
26	SW Bikini Atoll	3	-	3	Trolling
26	SE Bikini Atoll	4	-	4	Trolling
28	2,101U (SARATOGA)	4	-	4	Collected by divers in 90 ft - 210 ft of water
28	Between Bikini and Amen	2	-	2	Coral head (clam)
28	Between Bikini and Amen	7	-	7	Trolling
29	2,101U (SARATOGA)	7	-	7	Collected by divers in 90 ft - 210 ft of water
29	2,504 (CHILTON)	3	-	3	Fishing off fantail
30	2,899 Rokar	7	-	7	Poisoning in 2 ft - 4 ft water in reef flat
30	2,798 Rokar	13	305	318	Poisoning in 3 ft - 6 ft water on lagoon side
31	1,709 Amen-Bikini Spit	11	241	252	Poisoning in 30 ft water around coral head
31	Namu-Boro Spit	1	-	1	Found dead on beach
31	2,504 (CHILTON)	10	1	11	Fishing off fantail

Date of Collection	Area	Specimens Counted	Specimens Preserved	Total	Remarks
8/1/47	2,407 NW Bikini	1	-	1	Reef flat (spider snail)
1	2,797 Ion	22	365	387	Poisoning in 3 ft - 8 ft water on lagoon side
3	Kwajalein (PRINZ EUGEN)	18	2	20	Poisoning in 40 ft water
4	2,504 (CHILTON)	16	-	16	Fishing off fantail
5	1,092 Arji	25	606	631	Poisoning in 3 ft - 8 ft water on lagoon side
6	Between Bikini and Enyu	3	-	3	Trolling
7	2,796 Enyu	37	234	271	Poisoning in 25 ft water around coral head
8	Enyu Channel	-	1	1	Trolling
8	Enyu Channel	1	-	1	From stomach of 45 lb dogtooth tuna
12	Target Area	4	-	4	Trolling
12	Rongerik Atoll	15	-	15	Trolling
12	Arji Channel	6	-	6	Trolling
13	2,504 (CHILTON)	2	-	2	Fishing off fantail
14	0,891 Airy	28	46	74	Poisoning in 25 ft water around coral head
14	Rongerik Atoll	16	-	16	Trolling
14	Latoback (Rongerik)	-	180	180	Poisoning in 2 ft - 6 ft water on lagoon side

Date of Collection	Area	Specimens Counted	Specimens Preserved	Total	Remarks
8/24/47	2,000J (APOGON)	3	-	3	Still fishing off COUCAL
24	2,407 Bikini	-	1	1	Speared in surge channel on outer reef
25	SW Bikini Atoll	11	-	11	Trolling
	TOTAL	735	5148	5883	

Table I

NOTE: Table II is included in Secret Supplement to this report.

Figure 14. Radiobiology group picking up fish poisoned with rotenone along a reef off Namu Island. ABCR Photo No. 5100-3.

Figure 15. Dr. L.R. DONALDSON dissecting a fish in the Radiobiology Laboratory as Dr. F.H. RODENBAUGH Sr. looks on. ABCR Photo No. 5043-9.

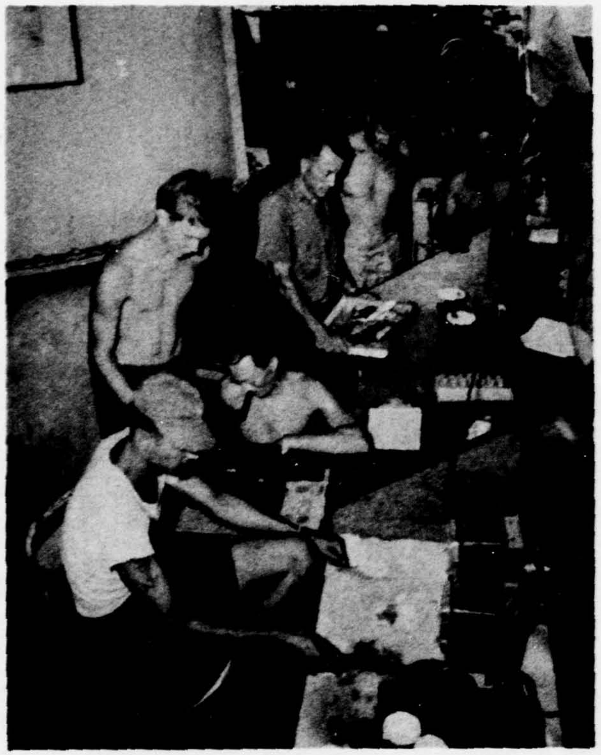

Figure 16. Radiobiology group at work in laboratory on the fantail of CHILTON (APA-38). Weighing and ashing of fish-tissue samples is in progress. ABCR Photo No. 5045-2.

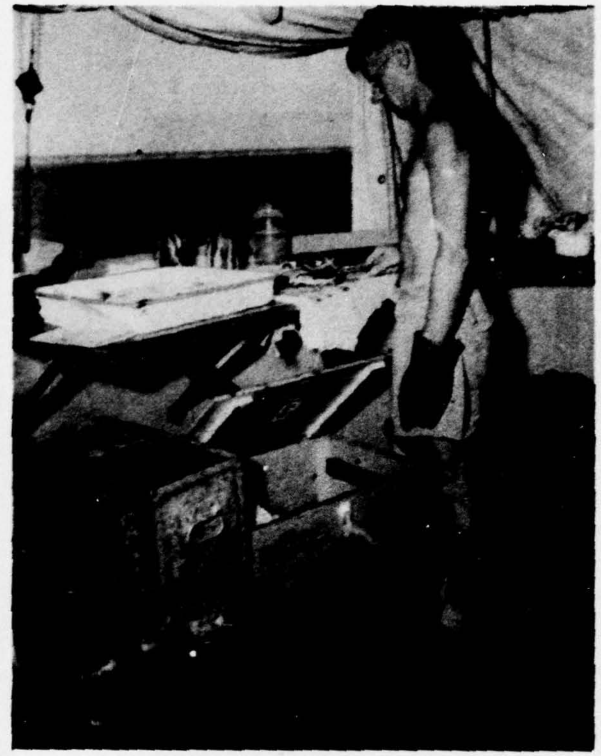

Figure 17. Dr. A.D. WELANDER examining samples in the Fisheries Laboratory aboard CHILTON (APA-38). ABCR Photo No. 5043-10.

3.005 Reef and Lagoon Fishes at Bikini

Reef and lagoon fishes are here defined as a group of species that habitually live in and about the coral reefs, either on the lagoon side or the seaward side of an atoll or in the lagoon itself. After reef-dwelling species attain adulthood, they are likely to remain more or less in one general area. It may be presumed, for example, that many of the adult reef fishes represented in the Bikini area during the summer of 1947 were there also during the summer of 1946.

Studies of reef and lagoon fishes were carried out by Mr. V. E. Brock, assisted by Dr. R. W. Hiatt and the group listed in Section 1.007. The investigations were centered primarily upon distribution and abundance, to be contrasted with results obtained in a similar survey made prior to Tests A and B in 1946. More particularly, they were intended to indicate, and possibly measure the following:

A. Whether any gross changes of the fish population had occurred as a possible result of Tests A and B.

B. Whether certain species of fish had become more or less abundant as a possible result of Tests A and B.

C. The foods eaten by various species, to indicate the probable paths of radioactive substances from bombs to fish.

The method used in the 1946 (prior to Tests A and B) survey of reef and lagoon fishes was also employed in 1947. The sea water in a measured area around or adjacent to a reef was poisoned by mixing rotenone-bearing material in the water. Killed and paralyzed fish in this area were then collected by dipping them up in nets, or picking them up off the bottom. The only special gear required in addition to the poison included spears, dip nets, and face masks for personnel doing the collecting underwater, although shallow-water diving gear was employed in some instances. Killed and paralyzed fish were collected as completely as possible, although it must be admitted that some recoveries undoubtedly were not made. It may be presumed, however, that the magnitude of error in 1947 was of the same order as that which obtained in 1946. It will be noted that this method of collecting was very similar to that employed by the Radiobiology Group, except that in the present case attention was centered upon poisoning a measured volume of water.

Test areas in and about Bikini Lagoon were selected upon two bases: using the poison effectively, and including areas which represented typical reef habitats; lagoon reefs, channel reefs, ocean reefs, and shallow ponds were included. The location of the Bikini fish population stations where studies were carried out in 1946 and 1947 is shown in figure 18. In addition, one other locality adjacent to the sunken Prinz Eugen at Kwajalein was investigated. Taken as a group, the test areas were representative of shallow-water reef areas in general.

Specimens were preserved in containers and returned to the Fisheries Laboratory in Chilton (APA-38). Here field identification of families and common species was made, and part of the fishes were dissected for purposes of examining their stomach contents (determination of food habits), and also in order to check upon the development of gonads. Figure 16 shows work in progress in the Fisheries laboratory. Some specimens were preserved and returned to the United States to be used as a basis for final identification or description of species. One group of tissue samples from the Kwajalein (Prinz Eugen) area was turned over to the

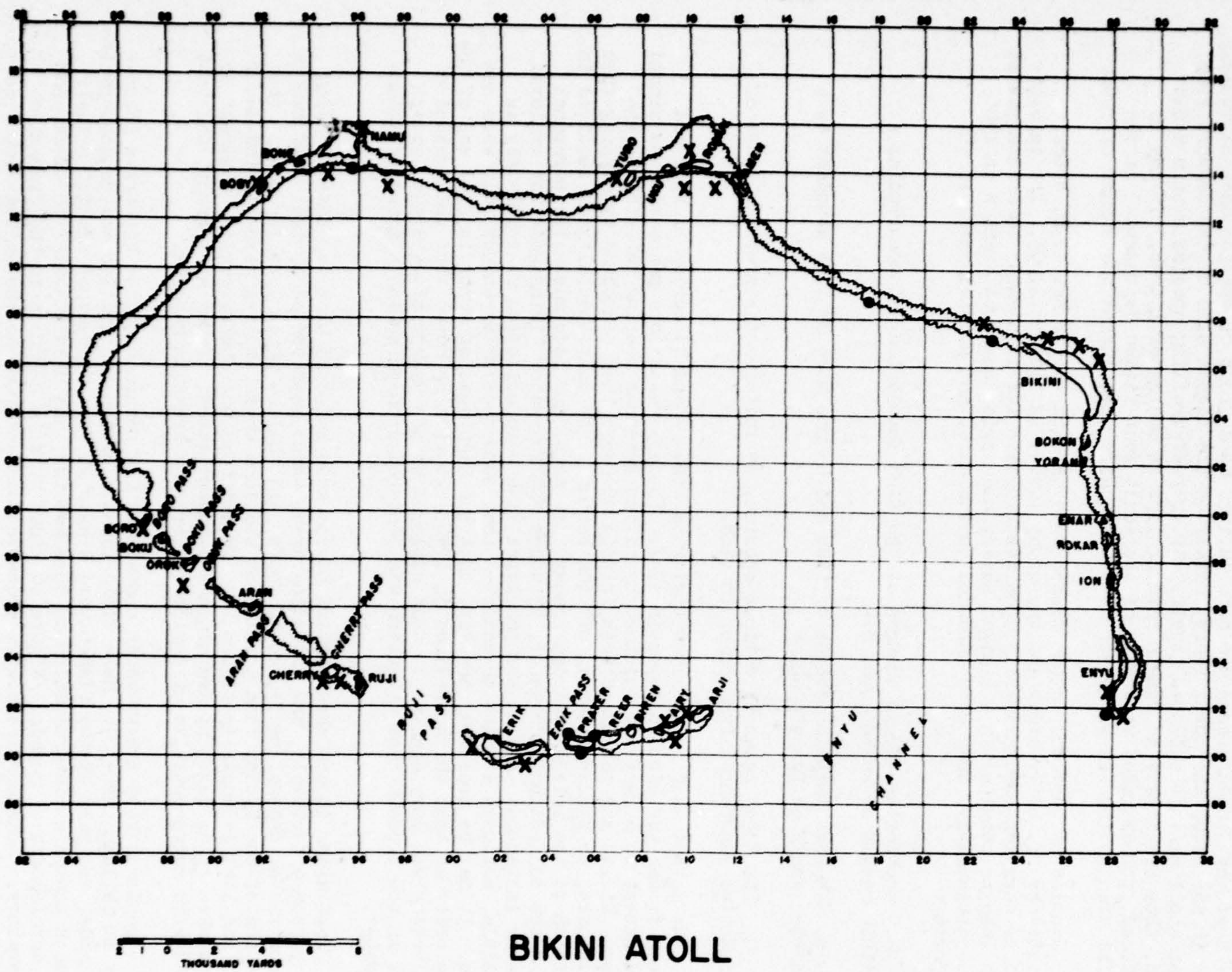

Figure 18. Location of Bikini Atoll stations where fish population studies were carried out in 1946 and 1947. Dots indicate 1946 stations and crosses mark the locations of 1947 stations.

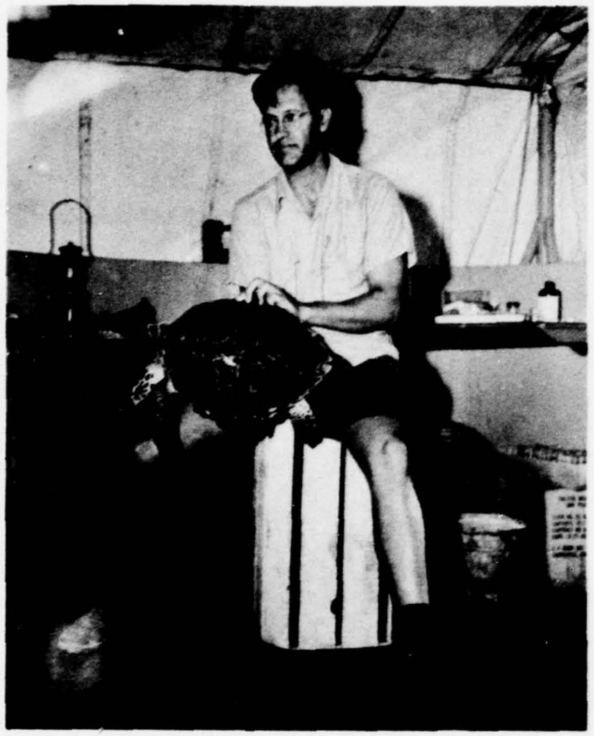

Figure 19. Mr. V.E. BROCK examining a turtle in the Fisheries Laboratory aboard CHILTON (APA-38). ABCR Photo No. 5095-12.

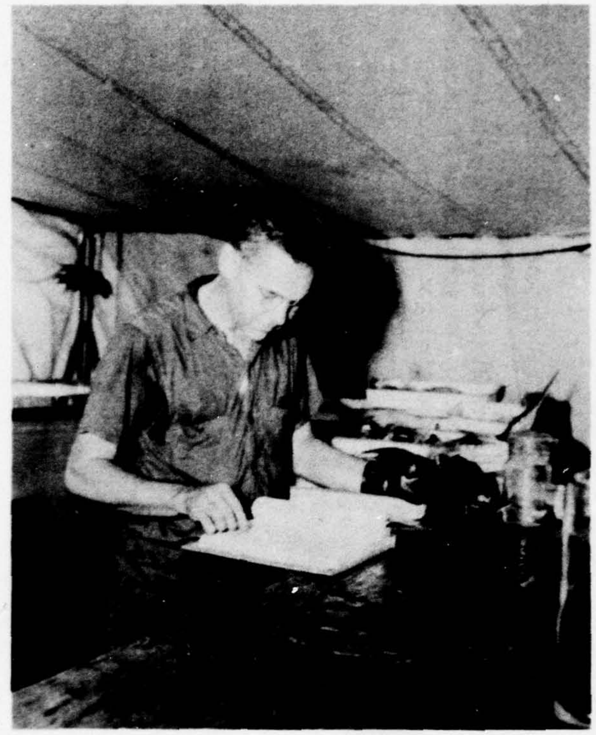

Figure 20. Dr. L.P. SCHULTZ at work in the Fisheries Laboratory aboard CHILTON (APA-38). ABCR Photo No. 5102-2.

Radiochemistry Group for analysis. Necessary laboratory facilities for the study of reef and lagoon fishes included instruments of measurement, common dissection instruments, containers, and preservatives.

Findings based upon field identifications and laboratory work done in Chilton (APA-38) are reported in the succeeding paragraphs. A final report based upon accurate identification of all species, and the establishment of species ratios will be prepared by Dr. L. P. Schultz, subsequent to the conclusion of proposed studies at the Smithsonian Institution. It is presumed that this report will be conveyed to the Secretary of the Smithsonian Institution, and thus to the Chief of the Armed Forces Special Weapons Project (see Section 3.007). Similarly, a final report upon food chains which involve the reef and lagoon fishes will be prepared by Dr. Hiatt at the University of Hawaii, for submission to the Chief of the Armed Forces Special Weapons Project at a later date.

Table III, which appears on the following page, shows the data on fish population obtained by poisoning measured areas with rotenone-bearing material during the 1947 resurvey, and compares these data with data for similar stations that were studied prior to Tests A and B. In this table the significant index is "fish per unit area" which is given in adjacent columns for 1946 and 1947. Inspection of these two columns shows that differences found were not great, and that they exhibit no indications of a trend or trends. Observed differences undoubtedly were too small to be significant in view of the errors which exist in population studies of this nature.

In view of the foregoing facts, it may be concluded that no significant change in the population of reef and lagoon fishes was evidenced at Bikini, measurable by the technique employed, when comparison is made between data gathered prior to Tests A and B and data obtained during the course of the resurvey. It would appear possible and no doubt probable that no permanent damage has been done to the population of reef and lagoon fishes at Bikini Atoll as a result of Operation Crossroads.

In addition to the foregoing studies, Dr. R. W. Hiatt made some investigations of food chains involving reef and lagoon fishes, anticipating the possibility that certain types of fish might exhibit marked population changes, and that these changes might be correlated with types of food eaters. Since no obvious population changes were in evidence, the data concerning food chains does not appear to have significance except as a contribution to the overall ecological study of the Bikini area.

Reef and Lagoon Fishes: Annex A

Annex A represents a preliminary account of Dr. R. W. Hiatt's studies of food changes involving the reef and lagoon fishes of Bikini Atoll. The objectives of the investigation were as follows:

A. To ascertain the food chains represented on the reefs of Bikini Atoll.

B. To provide a basis for more critical analyses of food consumed by those species of fish found to be radioactive.

C. To provide evidence for possible reduction in the relative abundance of certain species of fish after Tests A and B. This evidence, derived from feeding habits, presumably would indicate effects of radiation on the fish population gained indirectly through the consumption of radioactive food materials.

Dates	Stn. No.	Station Location 1947	Habitat Type	Est. Area • sq yds	No. of Fish	Fish per Unit Area 1947	Fish per Unit Area 1946	Stn. No.	Station Location 1946	Habitat Type 1946
7/18	S42-533	Sand spit-West End Bikini	Lagoon Reef	5,000	1,031	.206	.214 .148	S46-128 S46-48	Amen Island Romuk Island	Lagoon Reef
6/21	S46-442	About midway between Biki-ni & Amen (Beacon San)	Lagoon Reef	5,000	748	.149	.214 .148	S46-128 S46-48	Amen Island Romuk Island	Lagoon Reef
7/6	S46-508	Namu Island	Lagoon Reef	5,625	722	.128	.123	S46-50	Namu Island	Lagoon Reef
7/1	S46-483	Enyu Island	Channel Reef	2,000	736	.368	.481	S46-8	Enyu Island	Channel Reef
7/17	S46-405	Prayer Island	Channel Reef	3,100	510	.164	.246	S46-98	Cherry Island	Channel Reef
6/19	S46-441	Prayer Island	Ocean Reef	750	1,124	1.50	.405	S46-96	Airy Island	Ocean Reef
7/7	S-1019	Namu Island	Ocean Reef	5,000	780	.156	.155 .198	S46-382 S46-251	Oruk Island Yuro Island	Ocean Reef
6/18	S46-422	Between Pra-yer & Reer Islands	Shallow Pond	10,000	2,088	.209	.336	S46-10	Erik Island	Shallow Pond

Table III. Comparative data derived from the study of fish-population stations in 1946 and 1947.

As noted on the preceding page, objectives A and B proved to be of little consequence, if not impossible of attainment, for the reason that the 1947 reef and lagoon fish population was very similar to that observed at Bikini in 1946. However, the results are none the less important, and are reproduced here because they are an essential part of the interrelationships represented in the Bikini community. Dr. Hiatt plans to submit a more detailed report at a later date.

Fish were collected both on the lagoon side and seaward side of several islands including Prayer, Amen, Enyu, and Namu by poisoning with rotenone. Over 250 fish stomachs of 71 species representing 37 families were examined. Although many more species as well as families are found among the fish fauna of Bikini, those studied were among the most abundant and most important of the reef fishes.

In addition to actual stomach content analyses, many hours of observation with face mask and shallow-water diving gear were made. Through these observations many feeding habits were revealed, and the information obtained supplemented data derived by identification of stomach contents.

Figure 21 indicates the significant interactions of various plants and animals represented on and about the reefs of Bikini Atoll.

Algae form the basis of all food chains in the ocean. For the purposes of this investigation the algae of Bikini have been divided arbitrarily into three groups: (a) microscopic algae (algal fronds with large, branching thalli, and fine filamentous or encrusting types which grow on beach rock and dead coral), (b) microscopic algae (diatoms and desmids found at the surface of the various substrates on the reef), and (c) phytoplankton (suspended unicellular types).

Animals on the reef were divided into several groups for convenience in studying the sequence within the food chains. The following categories include the various reef dwellers:

A. Zooplankton (animals of small size and weak swimming ability which may be planktonic throughout their life history; or animals which represent the larval stages of crawling, swimming, or sedentary reef animals when adult).

B. Coral feeders (animals which consume living coral).

C. Omnivores (animals which consume a diet of both plant and animal matter).

D. Herbivores (animals which take only plant food).

E. Plankton feeders (animals which sieve the suspended animals and plants from the water).

F. Detritus feeders and scavengers (animals which live on the finely particulate remains of algae or animals; or animals which devour dead animal remains).

G. Intermediate reef-dwelling carnivores (smaller carnivores which consume herbivores, detritus feeders and scavengers, plankton feeders, or others of their own category).

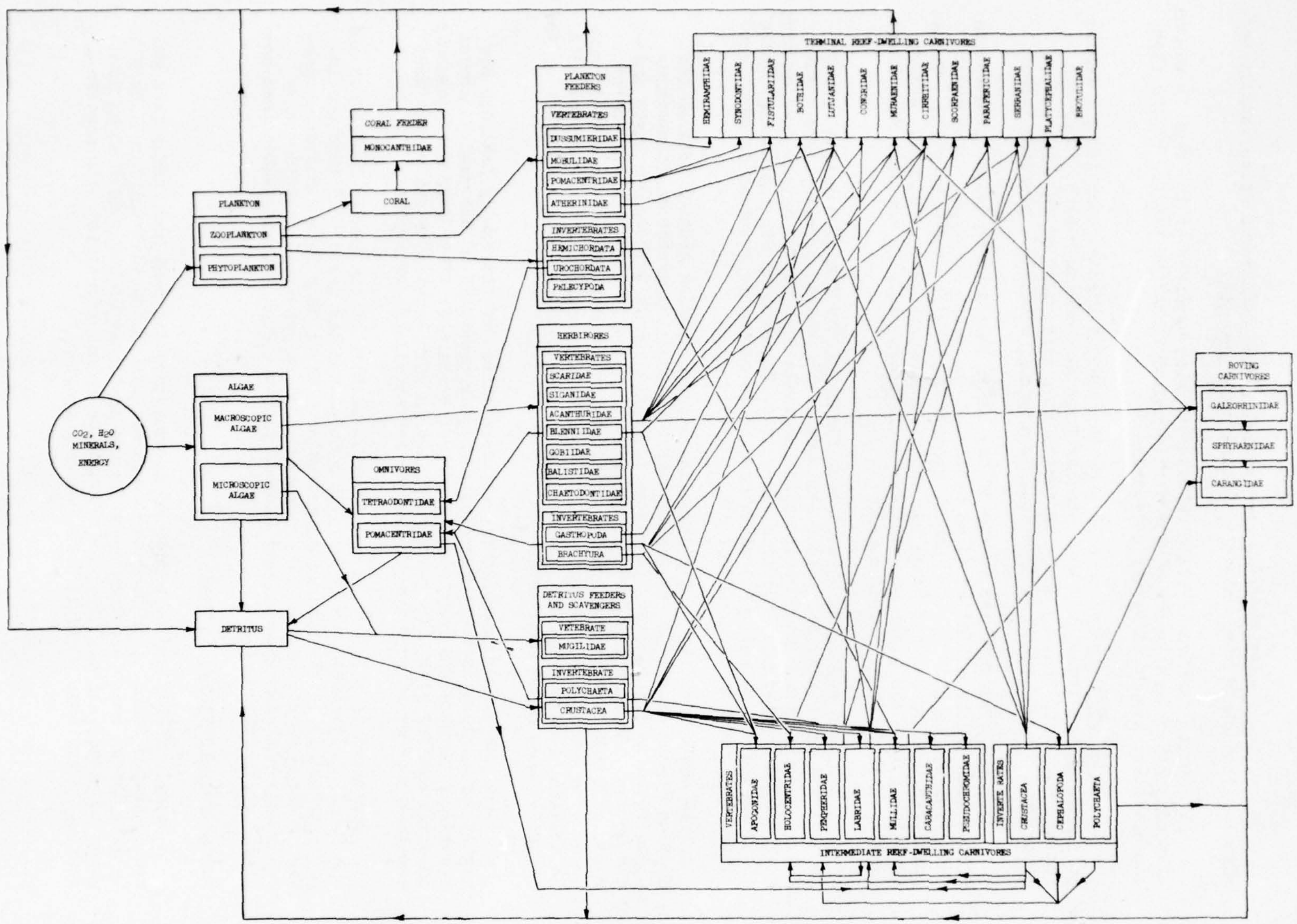

Figure 21. Diagram to indicate the nature of food chains involving the reef and lagoon fishes of Bikini Atoll. ABCR Photo No. 6000-7.

H. Terminal reef-dwelling carnivores (larger carnivores which usually terminate a food chain when they attain their full growth).

I. Roving carnivores (fish which cover wide expanses of the reef in search of food; they generally are of large size and of voracious habits, eating fish and invertebrates of all other categories).

It is of significance to note that the various species comprising a family of fishes almost invariably have similar food and feeding habits. Only one family, Pomacentridae, is an exception to this rule; most of its members are omnivorous but one species, Abudefduf leucopomus, often is a plankton feeder.

Of particular interest is one of the large monacanthids, whose stomach was filled with chunks of living coral mostly of the genus Acropora. Apparently this fish breaks off the tip ends of brittle coral with its heavy teeth. These coral fragments pass on through the entire alimentary canal unchanged, except that the polyps are digested. Insofar as is known, this is the only fish from Bikini which feeds on living coral.

It has been popularly assumed that fishes of the Family Scaridae (parrot fishes) and the Family Balistidae (trigger fish) consume corale polyps. This notion is erroneous. Many observations of these fish during active feeding show that they are grazers on the fine algae (both filamentous and encrusting) which grow on coral rocks and on coral heads. Tooth marks are apparent in such locations everywhere on the reefs of Bikini Atoll.

The members of the Family Siganidae deserve special mention because the species Siganus rostratus is perhaps the most habitual grazer on filamentous algae found in the lagoon. It occurs in great schools both on the reefs and on the bottom. Stomach contents and observations show it to be strictly herbivorous, although it was caught off the ship by hook and line in considerable numbers. The young of this species doubtless furnish many of the carnivores with an abundant food supply. Adult siganids have been taken from the stomach of the dogtooth tuna, Gymnosarda nuda.

Among the smaller carnivores, representatives of the Family Labridae are highly influential in the interrelationships represented on the reef. Labrids are very numerous, and many species thereof are small. They feed most commonly on still smaller fish and crustaceans, and in turn constitute one of the most abundant sources of food for the larger reef-dwelling carnivores.

Two types of carnivorous crustaceans, members of the Family Squillidae and the Family Portunidae, are especially abundant on the reefs, and thus are important factors in the biological potential. Since they have carnivorous habits, feeding mainly on smaller crustaceans and polychaetous annelids, they habitually hunt in comparatively exposed places. Such activity makes them easy prey for carnivorous fish.

3.006 Pelagic Fishes at Bikini

Pelagic fishes are here defined as those species that habitually feed and are otherwise found at or near the surface. This means that they are likely to be distributed over far-flung ocean areas, that they probably move about from place to place, and that they do not tend to become identified with one small area as in the case of adult reef-dwelling species.

Studies of pelagic fishes in the resurvey area were conducted by Mr. J. C. Marr, with the assistance of Dr. G. S. Myers, Dr. O. R. Smith, and the commercial fishermen listed in Section 1.007. These studies placed emphasis upon the abundance of various species; and especially upon changes in abundance, as contrasted with conditions found in 1946; and upon changes in relative abundance during the period of the 1947 resurvey. In addition, attention was centered upon the racial comparison of tunas found at Bikini with tunas known from other parts of the Pacific Ocean.

All of the larger fishes were caught through the use of trolling gear operated from picket boats. The trolling operations were conducted in the open sea surrounding Bikini Atoll and Ronjerik Atoll, and to a lesser extent in their lagoons. For purposes of catching some of the smaller fishes, a night-light platform was erected on LCI(L)-615, and a light employed either above or below water to attract certain species. A plankton net also was towed from LCI(L)-615 for purposes of collecting larval fishes and eggs at various depths up to about 100 fathoms.

Specimens taken by the various collecting methods were conveyed to the Fisheries Laboratory in Chilton (APA-38). Some fish were preserved for return to the United States, where they were destined to be used as the basis for further studies. Field identification, insofar as possible, was made of various families and species represented in the daily catch. Dissections of almost all fishes were carried out in the laboratory in order to determine the maturity of sex products represented in the gonads, and to identify and tabulate stomach contents in order to establish the position of these species in the food chain. In the case of tunas, comprehensive morphometric data were compiled for comparison with data on tunas taken elsewhere in the Pacific. Special gear required for these laboratory activities included instruments of measurement, containers, preserving fluid, and the common dissection instruments.

In addition to the conclusion recorded in this report, it is anticipated that two or perhaps three final reports will be based partially or wholly upon data obtained at Bikini, as follows:

A. A report upon levels of species abundance as represented in the Bikini Area.

B. A report upon the races and distribution of Pacific tunas (only partially based upon resurvey data).

C. A report upon the commercial fishing opportunities in the northern Marshall Islands area.

The foregoing reports will be prepared by or under the direction of Mr. J. C. Marr, and will be submitted to the Fish and Wildlife Service of the U. S. Department of the Interior. Report No. 1 will, of course, be of greatest interest from the standpoint of the Bikini Scientific Resurvey, but it is assumed that all three reports will be available to the Chief of the Armed Forces Special Weapons Project.

In order to attain the objectives of the pelagic fisheries program, three 45-foot picket boats, each under the direction of a skilled commercial fisherman, carried out routine trolling operations in the vicinity of Bikini Atoll. Similar trolling operations also were carried out in the vicinity of Rongerik Atoll, since the 1946 operations showed that the levels of abundance in the two areas were roughly the same. A total of 48 boat-days were fished at Bikini and

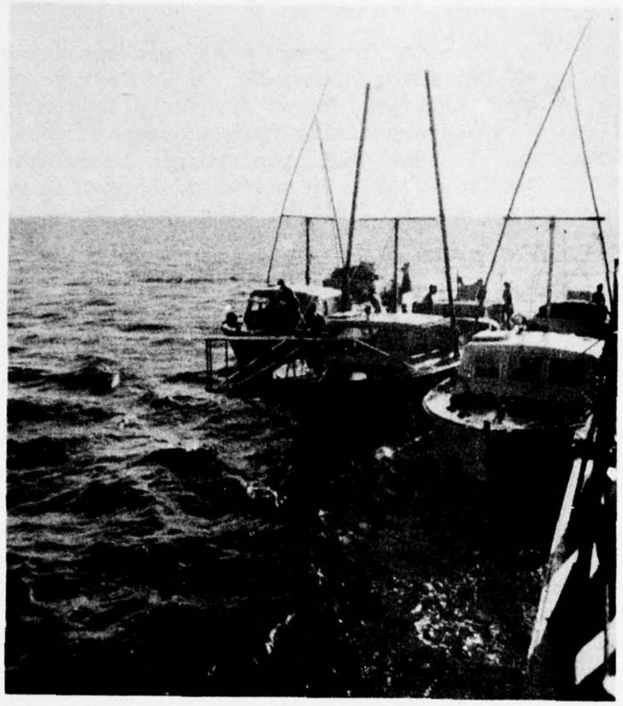

Figure 22. Three picket boats used in trolling by the pelagic fishermen. Note the "pulpit" extending out from the bow of the center boat. ABCR Photo No. 5064-10.

Figure 23. Mr. O. R. SMITH taking measurements of a fish in the Fisheries Laboratory. ABCR Photo No. 5033-11.

23 boat-days at Rongerik. Preliminary estimates of return in numbers of fish per unit-of-effort expended, indicate that the levels of abundance in the two localities were about equal during the 1947 operation. Should this conclusion be substantiated by a more detailed analysis of the data, it would seem obvious that the effects, if any, of Tests A and B on the abundance of the fishes taken in the pelagic fisheries survey were not evident in July and August of 1947.

In addition, the species composition of the catch in the two years was practically identical. The species entering the catch in 1947 were also taken in 1946, with two exceptions. These two exceptions are marked by a single asterisk in Table IV. Their addition to the species list almost certainly does not reflect any changes of radiological significance, but it is rather merely a matter of chance. Some species which were taken in 1946 were not caught in 1947. Again, this represents a matter of chance, as in the case of the marlin (Makaira sp.) -- only one was taken in 1946; or a matter of seasonal changes in abundance, as in the case of the dolphin (Coryphaena hippurus) which was abundant early in 1946 but absent from the area in the latter part of the operation.

During the 1947 operation a total of 691 fishes were taken. Of this total, 506 fish were caught near Bikini Atoll and 185 near Rongerik Atoll. The numbers for each species are given in Table IV.

The visceral cavities of practically all fishes caught were opened; sex and degree of maturity were noted, and stomach contents were tabulated. No gross abnormalities that could be considered due to radiation effects were noted. Various tissue samples were made available to the Radiobiologists for ashing; the results obtained are cited in Section 3.004. The stomach content data will yield (in conjunction with similar work done by Dr. R. W. Hiatt on reef fishes, and the work of the Radiobiologists) information on the possible paths of radioactive materials through the food chain. Biological data concerning the species of fish caught also included routine length and weight measurements, and notes on color patterns, ecology, and behavior.

A large series of morphometric data were taken from specimens covering the size ranges of the species marked by two asterisks in Table IV. A total of 215 sets of such data were obtained. These data will be used for comparison with similar data from other parts of the Pacific. The resulting racial studies will be of greatest value with reference to the yellowfin tuna and the oceanic skipjack, due to the commercial importance of these species.

Information bearing on the commercial fishing opportunities in the northern Marshall Islands area was accumulated in daily records and observations. Several samples of shark livers were preserved for further analysis of quantity and quality of oil contained.

Larval pelagic fishes were collected by Dr. G. S. Myers at the suggestion of Mr. O. E. Sette and Dr. L. A. Walford of the U. S. Fish and Wildlife Service. Methods employed included:

A. Collecting small or larval fishes that were attracted to an electric light (night) at the surface.

B. Towing of large young-fish trawls at different depths.

Both of these methods involved use of LCI(L)-615, when available, on whose forward starboard side a special platform for night-light fishing was erected.

SCIENTIFIC NAME	COMMON NAME	NUMBER
Gymnosarda nuda**	dogtooth tuna	298
Sphyraena sp. (little)	Little barracuda, plain	18
Aprion virescens	green snapper	6
Grammatorcynus bilineatus**	two-lined mackerel	21
Sphyraena sp. (big)	big barracuda	11
Caranx sp. (black)	black jack	9
Euthynnus yaito**	black skipjack	73
Katsuwonus pelamis**	oceanic skipjack	84
Elagatis bipinnulatus	rainbow runner	68
Neothunnus macropterus**	yellowfin tuna	77
Acanthocybium solandri	wahoo	11
Variola louti*	serranid	4
Lutjanus bohar	red snapper	4
Caranx stellatus	blue jack	2
Caranx sp. (big-eyed)	big-eyed jack	1
Cephalopholis argus	red grouper	1
Caranx sp. (spotted)	yellow-spotted jack	1
Sphyraena sp. (yellow-lined)	yellow-lined barracuda	2
	TOTAL	691

Table IV. Pelagic fish as taken at Bikini and Rongerik in the course of the Bikini Scientific Resurvey.

The young and larval fishes were taken both at Bikini and at Rongerik, and were preserved for future study in the United States. Such study presumably will be carried out by the U. S. Fish and Wildlife Service or by Scripps Institution of Oceanography.

A brief preliminary sorting and study of the young fishes obtained by Dr. Myers provided one interesting result. A species of small round-herring is the most numerous kind of fish in Bikini Lagoon. Within the lagoon, it is semipelagic, roaming about in large schools and feeding directly upon minute planktonic animals. It would, therefore, be one of the fishes most likely to suffer from the effects of radioactivity, either in the water or in planktonic organisms. Dr. Myers' collection of small fishes from near the target area is found to contain numerous growth-stages of this round-herring, from individuals not over 30 days in age up to adult. Moreover, his samples are found to be comparable with ones of the same species taken at Rongerik. It is probable that such complete growth-series have not been obtained for any other Bikini fish. The inference is that the population of this round-herring has not been seriously affected by Tests A and B, and that breeding is now going on normally in the eastern part of Bikini Lagoon.

3.007 Taxonomy and Teratology of Fishes at Bikini

Studies concerned with the taxonomy, morphology and teratology of fishes were conducted by Dr. L. P. Schultz, who also furnished an identification of species service for the other fisheries groups and for the Radiobiology Group. In addition to this taxonomic work, Dr. Schultz's studies were concentrated upon evidences of reproductory changes, or the possible disappearance of species subsequent to Operation Crossroads.

Methods of collecting specimens were the same as those employed by the other fisheries groups (see Sections 3.005 and 3.006). However, added photographic gear was brought into employment in order to obtain natural color photographs of living specimens. This is a necessary procedure in the case of tropical fishes, because the brighter colors in particular begin to fade very shortly after death. Harpoons also were used in taking manta rays, which are large, marine elasmobranchs. Specimens were collected inside and outside the lagoon at Bikini, at Rongerik, and at Kwajalein. Examinations of fish nests found in shallow water were made.

All fishes and related types were brought back to the Fisheries Laboratory in Chilton (APA-38), where adequate samples for later studies to be conducted in the United States were preserved and packaged. Field identifications, and enumerations of species were effected. Dissections were carried out for purposes of examining reproductory organs, and in general, to detect any teratological evidences that might be represented. Examinations of various post-larval fishes were made.

Findings reported here are complete for the period of the resurvey only. Additional work will be carried out at the Smithsonian Institution by Dr. L. P. Schultz, and by Mr. L. P. Woods of the Chicago Natural History Museum, provided adequate funds for support of the project are made available. Two reports are proposed, as follows:

A. A descriptive catalogue of the fishes in the Marshalls and Marianas, including about 400 species. This will be based upon about 15,000 specimens collected by the Naval Air Medical Research Unit in the Marianas, and upon about 50,000 specimens obtained at Bikini, including part of those mentioned in

Sections 3.005 and 3.006. A sample description of a species is included as Annex A to this Section. The descriptive catalogue will be as completely illustrated as possible, will contain keys for quick identification, together with color descriptions, and will include a statement on the ecology of each species.

B. A general report prepared by Dr. L. P. Schultz on reef fish investigations at Bikini, including a classification of habitats, the distribution of fishes, collecting methods, and species ratios. For the latter, final data will come from the report described in A above.

The foregoing reports, when completed, will be submitted to the Secretary of the Smithsonian Institution and will be available to the Chief of the Armed Forces Special Weapons Project.

Mention has already been made of the fact (see Section 3.005) that a survey of reef and lagoon fishes was conducted at Bikini Lagoon in 1946, prior to Tests A and B. Subsequently, the lagoon waters were subjected to blast and radioactivity effects, to contamination by oil from target ships, and to general pollution owing to the presence of ships and men in the area. Whatever the temporary effect of these factors may have been, no changes were observed in the fish fauna in 1947. Table V includes a designation of the 1947 collecting stations.

Of course population pressure from all sides is very great in an environment like that at Bikini, and it is axiomatic that if an area becomes depopulated but remains habitable it will promptly be repopulated by (a) reproduction of the indigenous fauna accompanied by an increased rate of survival, or (b) migration of individuals from contiguous areas. Such considerations may account for the fact that the fish population at Bikini appeared to be about the same in 1947 as it had been in 1946. For not only was this the case, but in addition, the species that were most numerous in 1946 still enjoyed the same rank in 1947, and no species found in 1946 appeared to be missing. As a matter of fact, six species taken in 1947 were not collected during 1946.

Larval and post-larval stages of surgeon fishes (Acanthurus triostegus), and the young of round herring (Family Dussumieridae) and lizard fishes (Family Synodontidae) were observed in the lagoon waters. Gobiodon citrinus was nesting among corals of the genus Acropora, and sharks exhibited normal embryos when dissected. Milt (containing sperms) was flowing readily from the shark pilot (Echeneis nacrautes), the damsel fish (Abudefduf sordidus), the surgeon fish, and the ocean skipjack (Katsuwonus pelamis). These facts are mentioned by way of indicating that reproductive processes of fishes appeared to be normal.

No evidences of teratological phenomena were discovered in the course of examining fish specimens, but more careful studies will be carried out on specimens shipped to the National Museum during the next two or three years.

In the process of studying the fish population at Bikini during 1947 various observations concerning other marine types were also made. It was found, for example, that the reef between Bikini and Amen Islands above the mean low tide level did not appear to be in as healthy a condition as it was in 1946. The blue Heliopora coral heads on the ocean reef opposite the sand spit at the western tip of Bikini Island were largely dead, whereas in 1946, the outer edges were formed almost entirely of living polyps. In 1947 the dead corals were covered by a fine, filamentous algal growth. Various reef situations at Namu and Bikini Islands are contaminated by tarry substances and oil from target ships; around such deposits animal life is scanty if not entirely lacking. These tar deposits, however, are not in evidence below the mean low tide level.

Station Number	Date	Locality	Number of Fish Specimens: Preserved	Discarded
S-46-402	7/15	Bikini Lagoon, Chilton anchorage	25	25
S-46-403	7/16	Prayer Island	2	--
S-46-404	7/16-18	Prayer Island	(Invertebrates)	--
S-46-405	7/17	Prayer Island, channel	309	201
S-46-421	7/17	Prayer Island	1	--
S-46-422	7/18	Prayer Island, pond	930	1,158
S-46-441	7/19	Prayer Island, surf	641	483
S-46-442	7/21	Bikini-Amen reef	603	145
S-46-458	7/20-8/10	Chilton anchorage	8	--
S-46-473	7/22	Aran Passage	8	--
S-46-474	7/27	Enyu Channel	1	--
S-46-475	7/27	Bikini reef - ocean side	10	--
S-46-476	7/28	Off Prayer-Erik Channel in lagoon $1\frac{1}{2}$ miles	1	--
S-46-477	7/30	Chilton anchorage	1	--
S-46-478	7/29/30	Boro Passage	3	29
S-46-482	7/31	Bikini reef - ocean side	50	--
S-46-483	8/1	Enyu - ocean reef	96	640
S-46-505	8/1	Namu	1	--
S-46-506	8/3	Kwajalein	37	20
S-46-507	8/5	Bikini Atoll - off West reef	100	90
S-46-508	8/6	Namu - lagoon	495	227
S-1019	8/7	Namu - ocean reef	397	383
S-1040	8/7	Enyu - deep water at channel	26	--
S-1041	8/14	Rongerik Atoll, Latoback Island - lagoon	217	181
S-42-533	8/18	Bikini reef, West end sand spit	520	511
S-42-564	8/18	Bikini reef, West end sand spit, high rock pools left low tide	114	--
S-42-565	8/16	Bikini - ocean reef	12	--
S-42-566	8/19	Namu Island	1	--

Table V. List of fish collections preserved during the 1947 Bikini Scientific Resurvey for the U.S. National Museum.

For two months after arrival in Bikini Lagoon early in 1946 it was possible to see objects in the water clearly at depths of over 100 ft. After the target ships assembled in June, however, the water became less clear, and objects at depths of 35 ft. to 40 ft. were barely discernable. During July and August of 1947 similar cloudiness of the water was observed, especially in the northeastern part of Bikini Lagoon. It was believed that disturbance of beach sands by wave action could not account fully for this increased turbidity, and since Rongerick Lagoon is as clear as it was in 1946, doubt must be cast upon any theory that cloudiness of the water is a seasonal phenomenon. An explanation which appears to be more acceptable is that an increase in microorganisms in the water has occurred, due to the large amounts of sewage that have been discharged into Bikini Lagoon. Actual concentrations of this sewage per unit of water volume may not be excessive, but it is well known that a very slight increase in the amount of fertilizing substances in water may give rise to a disproportionately great expansion of the microorganism population. The expansion begins when a certain threshold is passed, and phosphates and other chemical substances in the water become available for use by organisms.

In conclusion, it may be stated that, with the exception of the areas where tar is deposited on the reefs, little evidence of permanent damage to the marine fauna was found at Bikini Atoll in 1947, and observable changes probably could be assigned to biological rather than radioactive origins.

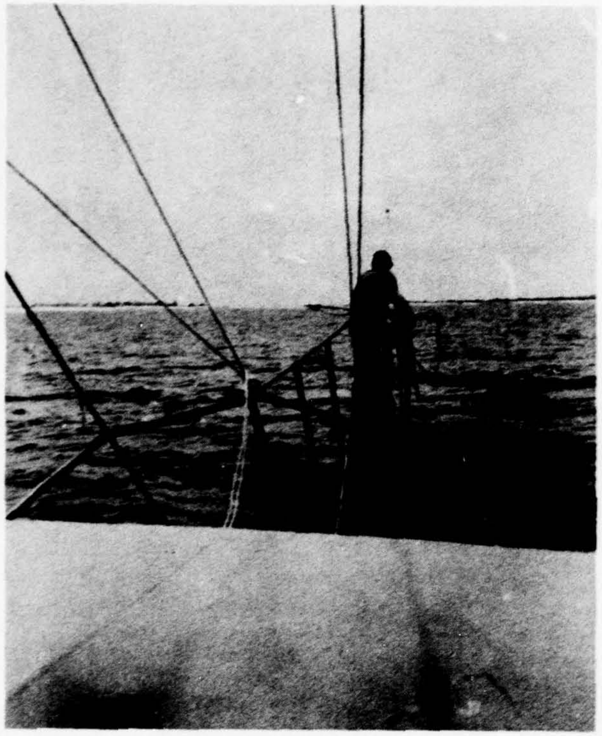

Figure 24. Fisherman in the pulpit of a picket boat, on the lookout for pelagic fish. ABCR Photo No. 5033-8.

Figure 25. LCDR R.L. REASER standing beside a shark taken from the deck of CHILTON (APA-38) in Bikini Lagoon. ABCR Photo No. 5047-1.

*SCORPAENOPSIS HECKEL

SCORPION FISHES

Scorpaenopsis Heckel, Ann. Wiener Mus., Vol. 2, No. 1, p. 158, 1839
(Type: *Scorpaena nesogallica* Cuvier and Valenciennes).

*SCORPAENOPSIS GIBBOSA (Bloch and Schneider)

Scorpaena gibbosa Bloch in Schneider, Systema Ichthyologiae, p. 192, pl. 44, 1801 (type locality America).

Specimens studied:

U.S.N.M. No. 140186, Bikini Atoll, Oruk Island, ocean reef, August 16, S-46-382, Herald, 1 specimen, 110 mm.

C.N.H.M. No. 44111, Rongelap Atoll, Mellu Island, lagoon reef, June 19, S-46-220, Schultz and Herald, 1 specimen, 109 mm.

U.S.N.M. No. 140185, Rongelap Atoll, Yugui Island, western side next to small boat passage, July 31, S-46-304, Herald, 2 specimens, 113 and 148 mm.

C.N.H.M. No. 44112, Eniwetok Atoll, Teiteiripucchi Island, lagoon reef, June 1, S-46-197, Schultz, 1 specimen, 134 mm.

U.S.N.M. No. 140187, Eniwetok Atoll, Rigili Island, May 30, S-46-189, 1 specimen, 65 mm.

U.S.N.M. No. 123735, *Marianas Islands, Rota Island, Sosan Isthmus*, October 1945, W. L. Necker, 1 specimen, 75 mm.

U.S.N.M. No. 124069, Marianas Islands, Guam, Ypao Point, August 1945, W. H. Markley, 1 specimen, 85 mm.

Description:

Dorsal rays XII,9; anal rays III,5; pectoral rays I,4 or 5, ix to xiii; caudal fin with 6 + 5 branched rays; pelvics I,5; gill rakers about 5 + 1 + 8; number of vertical scale rows from upper edge of gill opening to mid-base of caudal fin 43 to 45, and 22 to 24 pores in lateral line.

Depth 2.5 to 2.8, head 2.2 to 2.3, both in standard length; spout 3.2 to 3.3, eye 5.0 to 7.0, postorbital part of head 1.8, least depth of caudal peduncle 3.5 to 3.8, longest ray of pectoral fin 1.5 to 1.6, longest dorsal spine 3.0 to 3.8, all in length of head; least width of bony interorbital 0.7 to 0.9 in eye; least depth of caudal peduncle in its length 1.4 to 1.5; next to last dorsal spine in last dorsal spine 1.3 to 1.7 and in longest dorsal spine 1.4 to 1.8; length of first anal spine into second 1.9 to 2.1; pelvics reach to or a little past vent but not quite to anal fin origin.

The body is covered with ctenoid scales, mostly lacking on head except on the operculum. There are numerous dermal cirri almost everywhere on head and body but especially well developed on dentary, maxillary, preorbital, preopercle,

*The following is extracted from a report "Descriptive Catalogue of the Fishes of the Crossroads Operation", being prepared by Dr. L. P. Shultz and Mr. L. P. Woods of the Smithsonian Institution.

operculum, along the lateral line, and on various scales on body; a large dermal cirrus occurs at mid-base of caudal fin where there is a large dermal cirrus at end of scaled area; second anal spine equal to or a little longer than third; both about same thickness; tip of upper jaw with scarcely any concavity at symphysis, but tip of lower with a distinct symphyseal knob projecting a little beyond profile of snout; palatine teeth absent; a distinct pit below eye; area at anterior part of base of spiny dorsal with a high hump like that of a camel; when opened this hump was composed of muscular tissue and appeared normal; rays of soft dorsal notably longer than dorsal spines; no spines exposed at base of caudal fin; cranial spines exceedingly well developed and becoming many pointed with increase of age, some serrate in form; preorbital with one spine directed forward and another main spine downward and backward.

Color:

In alcohol, head and trunk generally barred and blotched with blackish and pale area; a black bar-like blotch extends from above pectoral fin base and rear of head dorsally covering the "hump" and the dorsal fin from third to fourth or fifth spine; the second prominent blackish irregular bar extends from soft dorsal fin across body including basal 3/4 of anal fin; base of caudal fin rays blackish and another dark bar across second third of caudal fin with distal 1/5 of caudal fin pale; pectoral blotched with blackish, forming two dark irregular bars across it with tips and center of fin paler; pelvic fins with central area black, the distal 1/5 of margin white; buccal membrane between premaxillary teeth and area inside these teeth at symphysis of upper jaw black, with a median white line; axil of pectoral fin with a black spot and sometimes a few additional black dots.

Color when alive:

The most outstanding color mark on this species was the ocellate black spot surrounded with bright orange on the posterior side of pectoral fin and its base.

Ecology:

This species is rather rare, at least in the shallower parts of the reefs where we took most of our specimens. It prefers an abundant growth of corals and algae occurring on both the lagoon and ocean reefs.

Remarks:

This species is the only one so far encountered in the northern Marshall Islands that has two spiny points on the nasal bone, and the only species with the posterior side of pectoral fin bright orange in color.

3.008 Invertebrate Embryology at Bikini

Studies primarily concerned with invertebrates embryology were carried out at Bikini by Dr. D.M. Whitaker, whose primary purpose was to test whether there existed in the period of the resurvey, any radiological effects upon normal processes of reproduction and development. A secondary purpose was to determine whether a number of marine animals are in breeding season in the Marshall Islands in July and August, and to note the types and sizes of eggs, and the ability of some of the species to hybridize, as a guide for future work of fundamental scientific interest in the fields of experimental embryology and general physiology that might in the future be carried out in the Marshall, Caroline, or Marianas Islands.

In all living organisms, cells that are dividing or proliferating rapidly are much more susceptible to damage by radiation (or other destructive agents) than are cells dividing less rapidly or not at all. The formation of reproductive cells (spermatozoa and ova), and the development of early embryos, involve the most rapid cell division in the whole life cycle of animals, and in consequence are relatively sensitive to radiation. (Note: examples of rapidly dividing and therefore sensitive cells in the adult body of the vertebrate are germ cells, blood cells, and cancer cells if present). Therefore, tests were made on the fertility and normality of development of a variety of marine animals collected at several places in the Bikini Atoll region known to have different degrees of radioactive contamination. A few sea urchins and other invertebrates also were collected and examined at the nearby Rongerik and Kwajalein Atolls. Animals observed and tested in the Marshall Islands include sea urchins (Echinoderms), holothurians or sea cucumbers (Echinoderms), snails, clams, annelid worms, crabs, and shrimps, but most of the work was carried out on six or seven species of sea urchins, because these classical animals are among the most prolific as well as the most thoroughly studied in the sea, and also because most species do not move about to any great extent after metamorphosis, and therefore mature individuals taken from a given locality presumably have been there or thereabouts ever since the end of the comparatively brief pelagic stage of the embryo. Large mature sea urchins found on the reefs of Bikini Atoll in the summer of 1947 presumably were there when tests A and B occurred.

Sea urchins were taken for comparison from the relatively uncontaminated seaward reefs of Prayer and Namu Islands, at stations shown as P and N on the accompanying map of Bikini Atoll (fig. 26), and from a similarly uncontaminated region of the seaward reef of Bikini Island (station B1, fig. 26, and more exactly in fig. 27 at 165°-33'-20" E; 11°-37'-30" N). They also were taken from near the tip of the sand spit extending northwest from Bikini Island (station B2a, fig. 26, and more exactly in fig. 27 at 165°-30'-26" E; 11°-38'-19" N) and from the adjacent outer edge of the seaward reef (station B2, fig. 26 and more exactly in fig. 27 at 165°-31'00"E; 11°-38'-19" N), as well as from the broad reef between B2 and B2a. This reef northwest of Bikini Island showed some radioactivity at the time of the resurvey. Sea urchins also were collected just off the southeast tip of Bikini Island at station B3 (fig. 26, and more accurately in fig. 27 at 165°-32'-50" E; 11°-36'-5" N) which was only very slightly radioactive. In addition to the foregoing sources, specimens were dredged by geologists from a coral head in Bikini Lagoon in 40 ft. to 80 ft. of water (station CH, fig. 26); one was brought up by deep-sea divers from the flight deck of Saratoga; and specimens were collected on the seaward reefs of Rongerik Island, Rongerik Atoll; and Carlos Island, Kwajalein Atoll.

Most of the collecting required no special equipment other than ordinary buckets for transporting animals, a thermometer for measuring water temperature, and a Geiger counter. The latter instrument was used to measure beta and gamma

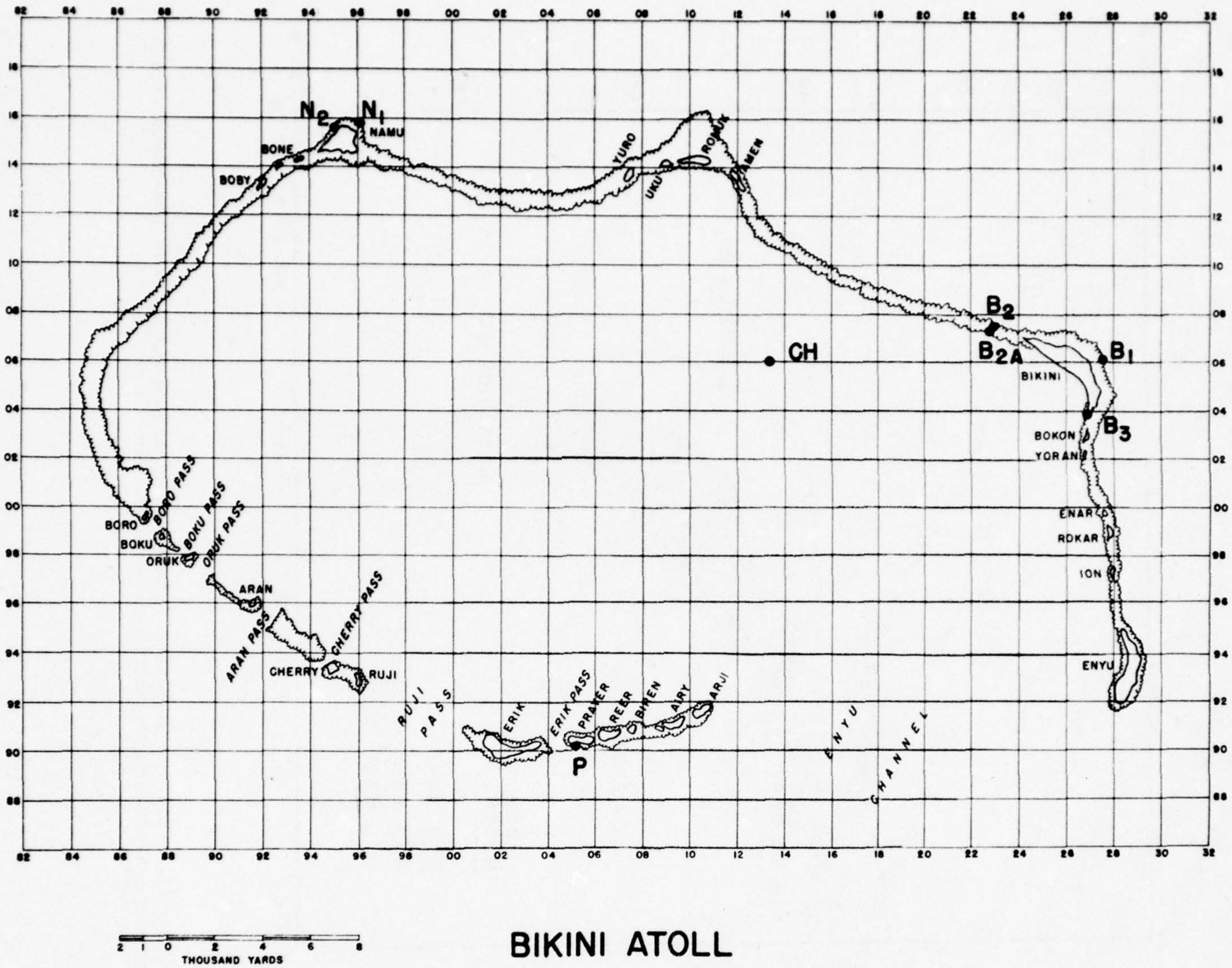

Figure 26. Collecting stations involved in the study of marine invertebrate development.

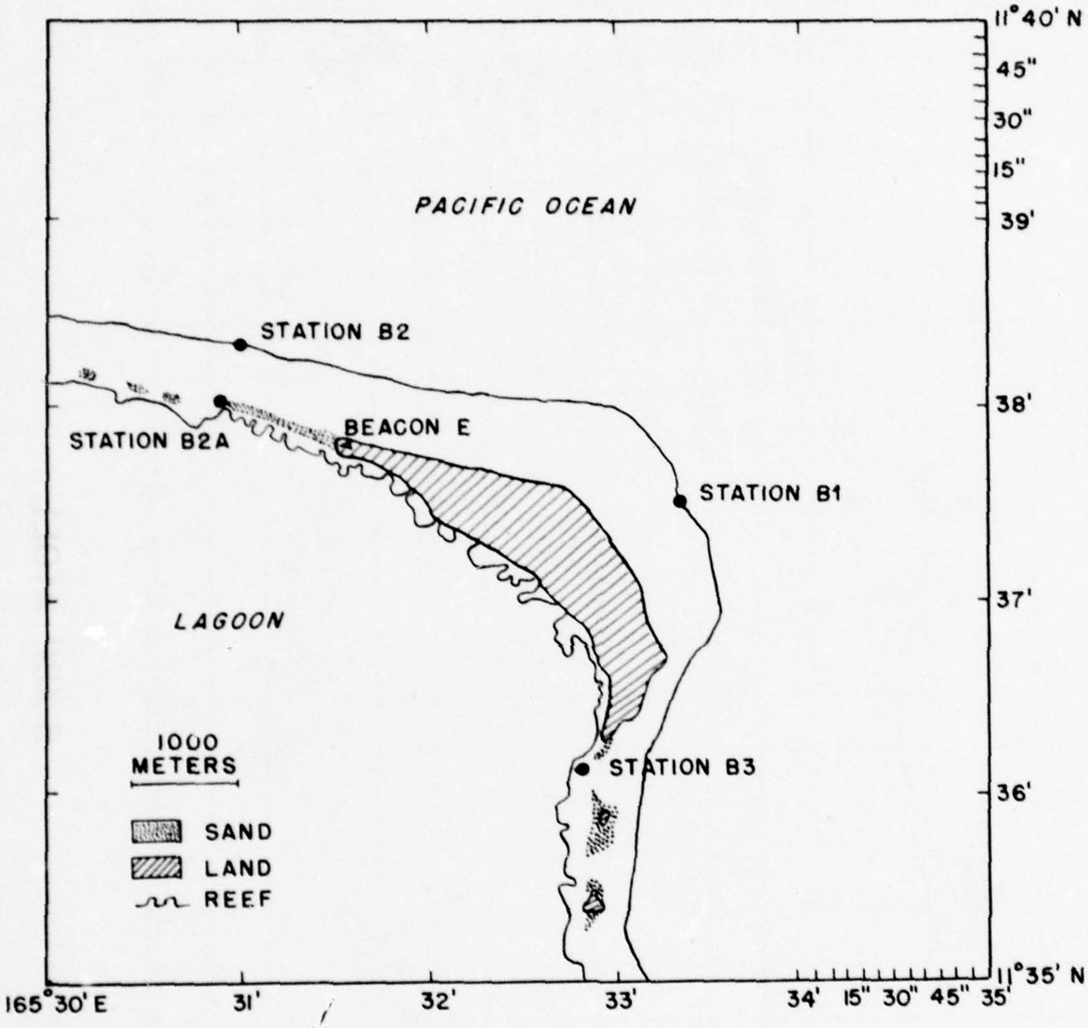

Figure 27. Stations on Bikini Island and adjoining reefs where specimens of sea urchins and other invertebrates were collected.

radiation in areas from which specimens were taken. Specimens from Bikini Island stations were removed to one of the Experimental Biology Laboratories (see Section 2.006), where ordinary biological equipment including microscopes, dissection instruments, and culture bowls and dishes were available. Temperature in the laboratory varied between 26°C and 32°C. The surface temperature of the ocean was about 28°C, while lagoon surf temperature varied between 28°C and 31°C. Shallow tide pools in the sun on the seaward reef reached temperatures above 40°C.

Studies were conducted as follows:

A. Autopsy of adult sea urchins and other invertebrates, and tests for fertility or sterility (gonads without gametes).

B. Beta and gamma counts of entire animals and of their viscera by means of a portable Geiger counter. These measurements substantially underrate the true radioisotope content of the animals, when, as in this work, a limited area of organism is exposed to the instrument. Measurements are of value nevertheless, for purposes of comparison and approximation.

C. Fetilization tests to indicate the quality and condition of eggs and sperm.

D. Observations of development to detect any abnormalities that might be attributable to the effects of radiation.

The results of these observations and experiments are reported in the succeeding pages. No large-scale continuing studies are planned, although Dr. Whitaker may investigate some related phases of the general subject upon return to the United States. Any results obtained will be freely available to the Chief of the Armed Forces Special Weapons Project.

Observations and experiments on sea urchins. The great slate pencil sea urchin (Heterocentrotus trigonarius) was found in abundance on the outer edge (lithothamnion ridge) of the seaward reefs of all islands visited, being especially abundant where waves driven by the northeast winds break directly and freely. These sea urchins attain great size, some spanning more than 17 in, including spines; sections of the bases of the large spines show 16 or more growth rings. It is not known whether these rings are annual, but they may well be. Throughout the period of the resurvey these animals were found to be in full ripe breeding season at every station from which they were collected on Bikini and Rongerik Atolls. All adult animals (i.e., those with tests over 3 in. long and overall lengths exceeding 12 in), both male and female, gushed forth large quantities of spermatozoa or eggs from swollen gonads when broken open. The egg diameter is approximately 0.072 mm. Small individuals, however, were sexually immature, and intermediate sizes were transitional. Specimens taken from Carlos Island of Kwajalein Atoll yielded some eggs and sperms, but even large animals often were sexually immature. Their lack of reproductive vigor was in striking contrast to the situation found at Bikini and Rongerik Atolls, and it is suggested that they may have been damaged by some concomitant of port activity and shipping, such as oil which was detected on the reef.

At Bikini, studies were first made on slate pencil sea urchins at station P on Prayer Island (fig. 26). This station was selected as a place to find the most normal sea urchins because it is in an area of the atoll that was least contaminated by Tests A and B, and today radioactivity at station P is negligible, being no greater than the natural radiation at Denver, Colorado. Some 37 slate pencil sea urchins from station P were opened and examined, and portable Geiger-

counter measurements made on them yielded the same readings, that were obtained on the reef. Sixteen were ripe females, and the remaining 21 were ripe males. The germ cells of 10 were observed microscopically during artificial insemination, and found to fertilize normally in more than 99% of cases. Normal cell division and early embryonic development followed. Adults from station N1 (fig. 26) on the seaward reef of Namu Island also were invariably ripe. Slate pencil sea urchins were next tested from station B1 on Bikini Island (fig. 26 and fig. 27), were radioactivity now is exceeding slight, and was not great at the time of Tests A and B. Fifty-six animals were tested from station B1, 27 being females and 29 males. Geiger-counter measurements showed intact animals and their viscera to give the same readings as those obtained on the reef. All 56 animals were sexually ripe, and eggs from 12 and spermatozoa from 14 were observed under the microscope and found to undergo normal fertilization in 99+% of cases. Fertilization was followed by cell division and production of pluteus larvae in about 48 hours.

The third station was B2 (fig. 26 and fig. 27), in a region of the reef over which great quantities of extremely radioactive sea water, laden with fission products, passed immediately after Test B. The reef to the northwest of Bikini Island was the most radioactive at the time of the resurvey, occasional small patches of tar on the beach of the sand spit near station B2a (fig. 26 and fig. 27) being quite active (e.g., 0.6+ r/24 hr). The general level of activity on the reef at B2 and between B2 and B2a (fig. 27) was found to be about 0.001 r/24 hr, or five times general background on Bikini Island. Occasional rocks on the lithothamnion ridge at B2, and also between B2 and B2a showed five or more times this general activity. Seventy-seven adult slate pencil sea urchins from station B2 were examined; 32 were found to be ripe females and 45 ripe males. Geiger-counter readings on intact animals were about four times background, while viscera were five times background, or equally as radioactive as the reef from which they came. By far the greater part of the radiation measured was beta, but gamma was detectable. Eggs from 15 females and sperm from 27 males were observed under the microscope, and without exception more than 99% of the eggs fertilized. Normal cell division and development to pluteus larvae followed. In other words, germ-cell formation, fertilization, and embryological development were entirely normal even in slate pencil urchins from the most radioactive reef at Bikini. Dr. L. R. Donaldson stated that many slate pencil sea urchins were found dead in this region just after Test B, killed presumably by radiation, or possibly by oil. At the time of the resurvey the survivors appeared to be fully recovered in their capacity to reproduce.

Another sea urchin, Echinometra mathei, which is small and elongated, lives in burrows under pieces of coral rock on the reefs. Once settled, these animals probably do not move about. They were not in nearly such lush breeding condition as the slate pencils, but eggs (diameter 0.065 mm) and sperms were obtained from some individuals and gave excellent normal fertilization and development to pluteus larvae. They were taken near B1 and also between B2 and B2a (fig. 27); i.e., from non-radioactive and from radioactive reefs, but no differences could be detected. Specimens of this species of sea urchin always were less radioactive than the reef between B2 and B2a from which they came, probably because of selective food habits. Large numbers of healthy young animals were growing on the radioactive reef. Incidentally, it was found that sperms from this species will fertilize slate pencil eggs and form healthy pluteus larvae, but slate pencil sperms will not fertilize Echinometra mathei eggs.

A third sea urchin, Tripneustes gratilla, was collected near B2a and halfway out toward B2, and also near B3 (fig. 27). The tests or shells of the animals ranged from 2 to 3 1/2 in. in diameter, and the animals lived on sand which they freely ingested. Animals from the region between B2a and B2 typically yielded

Geiger counts four or five times background, and their viscera yielded counts of five or six times background. These readings correspond to more than 0.001 r/24 hr, and the specimens in question were the most radioactive sea urchins taken from the surface reefs. One of these animals was analyzed by the Radiochemists and Ce was found to be the principal radioisotope present. Tripneustes collected near station B3 showed a Geiger count of less than two times background, like the sand from which they were taken and which they pass through the gut. Tripneustes from all regions were in excellent breeding condition, although their gonads were not so swollen as those of the slate pencils. Occasional immature eggs mixed with mature ones suggested that the peak of the breeding season was still ahead. Eggs and sperm from many individuals were tested, and invariably more than 99% fertilized, with normal cell division and development to pluteus larvae following. No differences were found in the more radioactive animals. The eggs are transparent and 0.085 mm. in diameter. Practically all animals opened contained ripe gametes. Spermatozoa of Echinometra mathei did not fertilize Tripneustes eggs.

A fourth species, Echinothrix calamaris, which bears poisonous spines, was collected on the reef flat near B2a, and also at B3 and on the seaward reef of Namu Island at N2 (fig. 26). This species has alternating green and yellow bands on the spines; large black individuals lacking bands on the spines may be the same species or may be another species. Both types, and intermediate forms, were found at all of the collecting stations referred to above. Animals of both color patterns gave approximately the same Geiger-counter reading as the sand and coral from which they came, the viscera being slightly more radioactive than the shells. Animals from near station B2a yielded readings about five times background, while animals from B3 read less than twice background. These sea urchins appeared to have passed the prime breeding season at the time of the resurvey, but it was possible to obtain sperms and eggs from some individuals. The latter always fertilized and developed into normal pluteus larvae. The eggs are transparent and are approximately 0.067 mm. in diameter in the case of the black females, and 0.070 mm. in those with green and yellow banded spines. Urchins of the two color patterns hybridize readily in either direction, giving rise to good pluteus larvae, but black individuals tested with Tripneustes would not fertilize in either direction.

The proportion of animals yielding gametes was somewhat greater at B3 (60% of 52 animals) than near B2a (30% of 37 animals). However, this fact apparently was due to higher water temperature near B2a, where the temperature exceeds 40°C at sunny low tide, compared with a maximum temperature of the lagoon surf at 31°C at B3. One is led to conclude that the high water temperature has hastened ending of the breeding season rather than that the latter is a radiation effect, because similar animals collected on the seaward reef of Namu Island at station N2 (fig. 26), where there is virtually no radiation but where the reef water becomes warm as at B2a, are even more depleted and more devoid of eggs and sperms than are the animals from near B2a.

At the end of July one specimen of a small unknown species of sea urchin was taken from the flight deck of Saratoga by deep-sea divers. The diameter of the test was 7/8 in, and wide longitudinal rows or sectors of red and green color alternated. Short, delicate spines occurred in the red sectors. Geiger-counter measurement of the shell and exposed viscera showed 20 times background, almost all beta. Autopsy revealed plump ovaries filled with full-sized eggs (appr. 0.120 mm. in diameter) that had not yet undergone meiosis. This sea urchin was by far the most radioactive animal encountered, and had presumably spent its whole sedentary life of not more than a year on Saratoga's deck. Even so, the production of eggs was not inhibited.

On August 6th a number of small olive-green sea urchins (species unknown)

were dredged from a coral head in Bikini Lagoon (station CH, fig. 26) at a depth of between 40 ft. and 80 ft. Their tests were 1/2 in. to 3/4 in. across, and spines were about 1/2 in. long with yellow bands near the tips. The Geiger counter showed negligible radioactivity. These small sea urchins were sexually mature, and fertilization, cell division, and development to pluteus larvae was active and normal. Eggs were transparent, and about 0.107 mm. in diameter.

Two other species of burrowing sea urchins, Echinometra oblonga and Echinostrephus aciculatus were observed living on reefs (the former almost as far out on the lithothamnion ridge as the slate pencils), but their germ cells were not tested. The shells of at least one species of heart urchin and one species of sand dollar were found frequently on the beach, and a living cidarid sea urchin was found at Rongerik by Dr. P. M. Brooks.

Slate pencil sea urchins and Echinometra mathei develop at about the same rate, forming skeletal spicules 18 hr. to 20 hr. after fertilization, and well developed plutei before 48 hr. Tripneustes develops somewhat more slowly, and both Echinothrix calamaris and the associated black poison spined sea urchin develop still more slowly. The little olive-green sea urchin from station CH develops most rapidly of all, forming advanced plutei in less than 24 hr. in the laboratory.

Observations on other invertebrates. A number of invertebrates were examined for reproductive capacity. They were taken from a variety of localities about Bikini Atoll, some radioactive and others essentially not. The latter will be considered first. A large armless starfish (Culcita novae-guinae), some 8 1/2 in. across, was obtained from 10 ft. of water in the lagoon off Prayer Island. Autopsy showed it to be a vigorous male with highly motile sperm. A female spiny lobster (Panulirus) from the seaward reef of Prayer Island was found to be carrying large quantities of healthy young embryos attached to her abdominal hairs. A small female shrimp collected at the west end of Prayer Island carried healthy young with eyes. A female coconut land crab (Birgus latro) was caught in July on Prayer Island while releasing myriads of actively swimming young zoeas into the surf, and in August a similar release of young larvae into a bucket of sea water was observed on Namu Island by Drs. Schultz and Hiatt. During the period of the resurvey, gonad tissue from five giant Tridachna clams (measuring 20 in. to 32 in. across) was examined microscopically. Three of the clams were from coral heads in Bikini Lagoon at 25 ft. to 40 ft. depths, and two were from shallow water at the west end of Namu Island. The gonads of all five of these giant clams contained great quantities of well developed pear-shaped eggs (about 0.120 mm in diameter when spherical). No sperms were observed.

A variety of invertebrates were taken from the broad reef lying between stations B2 and B2a. As previously noted, the general radioactivity of this region is about 0.001 r/24 hr, with rocks here and there showing five times that figure. Furthermore, occasional small tar patches on the beach rock near B2a sent the Geiger counter off scale at 0.6 r/24 hr. Numerous females of three species of crabs taken from this reef carried healthy young in all stages of development up to hatching zoea larvae. One female tide pool shrimp carried advanced embryos. One species of annelid worm exuded eggs. A number of snail egg masses, collected under rocks, contained snail embryos in various stages of development from cleavage to swimming veliger larvae. A number of shelled gastropod snails were taken on the lagoon side of the sand spit near B2a from beach rock measuring 0.1 r/24 hr. on the Geiger counter, but the snails themselves measured less. On autopsy, females were found to contain good large eggs (0.150 mm. in diameter) and males yielded long-tailed motile sperms. An egg mass from another species of snail, thoroughly mixed with sand, which gave a reading of 0.001 r/24 hr, was reared in the

laboratory. Within a week large numbers of ciliated embryos with small shells emerged. A paper-shelled species of clam attached under rocks was found to be reproducing actively. Three Tridachna clams of a small reef species ranging from 2 in. to 4. in across, and having brilliant purple or green mantles, were autopsied; two were males with very large motile sperms, while the other was a ripe female with an abundance of pear-shaped eggs (0.105 mm. in diameter when spherical). A third species of Tridachna clam, a small one with yellow flutes on the shell, provided two specimens, both about 7 in. wide. One, from the reef referred to above, was a ripe male with motile sperm. The other was collected by diving on a radioactive coral head in the lagoon not far from station B2a. The latter animal registered 0.02 r/24 hr. on the Geiger counter, and turned out to be a ripe female with an abundance of pear-shaped eggs. A dozen specimens of the common black sea cucumber Holothuria atra, which occurs in great abundance on all reefs visited in the Marshall Islands, were collected between stations B2 and B2a from sand which gave a Geiger-counter reading of 0.001 r/24 hr. The viscera of these animals, through which large quantities of coral sand were passing constantly, read 0.001 r/24 hr. to 0.002 r/24 hr, and the intact animals read somewhat less. Six of these sea cucumbers turned out to be ripe males, with great quantities of motile sperms, and the other six were females whose ovaries were gorged with brilliant red eggs (0.140 mm. in diameter) that had not yet undergone meiosis. One large brown sea cucumber of a species that lives farther out on the reef proved to be a ripe female with an abundance of colorless diploid eggs (0.120 mm. in diameter).

Summary. The general picture presented by the invertebrate animal life of Bikini Atoll at the time of the resurvey was one of health and abundance, comparing very favorably with the faunas studied at Rongerik and Kwajalein Atolls, which received no radiation as a result of Tests A and B. A wide variety of invertebrate animals at Bikini Atoll are carrying on reproductory activities vigorously and normally. This is as true on the reefs northwest of Bikini Island (which have the greatest residual radioactivity today) as upon reefs which have exhibited no radioactivity at any time.

Animals observed and tested include notably the sea urchins, upon which the most extensive and crucial tests were made, and also a variety of clams, snails, worms, shrimps, crabs, and sea cucumbers.

It thus appears that invertebrates of the species tested which survived Test B, or which may have been produced since Test B, now are in normal health and reproductive activity at Bikini. No signs of mutations attributable to radiation from the atomic bombs have been found, but most types of mutations have not had time to reveal themselves.

At a future time, when several generations of plants and animals have been produced, it may be worth while to look for mutant forms at Bikini, even though the vast majority of any mutations induced by Tests A and B could not be expected to establish themselves under natural conditions.

3.009 Vertebrate Embryology at Bikini.

Studies of vertebrate development at Bikini were concerned primarily with the question of whether or not any effects traceable to radiation would be discovered. In a sense, these studies paralleled the investigations made by Dr. D. M. Whitaker in the case of invertebrates (see Section 3.008). The vertebrate studies were conducted by Dr. G. S. Myers.

Attention was centered upon lizards, which are the only terrestrial vertebrates present in large number in the Bikini area, except for the birds. Birds, to be sure, are well-represented on some islands of Bikini Lagoon, but being able to fly and to migrate, there was no assurance that individual birds at Bikini in 1947 had also been there in 1946. On the other hand, mature lizards found in the process of the resurvey were almost certainly in the same general areas during Operation Crossroads. Moreover, more or less the same species of lizards are widely distributed and well known in Oceania, and four of these species are found at Bikini Atoll, although one is not common.

Mature lizards were collected principally upon Bikini and Prayer Islands, and at Rongerik Atoll, where radiological contamination is absent. No special gear was required for this work except containers and preserving fluid. A small-bore gun loaded with shot cartridges was employed to bring down some of the more agile specimens. Female lizards were examined for the presence of eggs, and young lizards were studied both as to relative abundance and as to the existence of any structural abnormalities. Common dissection instruments were employed in this laboratory phase of the investigation. While it is difficult or impossible to attempt fertilization experiments with lizards in the field, a good index of population-fertility may be obtained by employing the methods outlined above.

Four species of lizards, two geckos, and two skinks were found both at Bikini and at Rongerik. However, not enough specimens of the brown skink were taken in either area to serve as a basis for any conclusions.

The striped skink proved to be very common at Bikini and Rongerik. The presence of numerous young (less than one year old) on Bikini Island indicates that Tests A and B had little or no effect upon normal fertility of the species. Egg-bearing females were not found, but it is probable that this fact merely meant that the resurvey was not at Bikini during the breeding season of the striped skink.

Both species of geckos appear to be equally abundant on Bikini Island and on Rongerik Island. On Bikini Island they commonly are found in and about structures erected in the course of Operation Crossroads. Adults and young (less than one year old) of both species were obtained. Fertile eggs of the larger gray gecko were found in damp soil; one egg was allowed to hatch and one was preserved.

No structural abnormalities were observed in any of the lizards taken at Bikini Atoll in 1947. To be sure, histological studies were not made, and microscopic structural changes may have existed. However, the evidence is against their occurrence except to the extent that they normally exist in nature. It may be pointed out in passing that teratological young probably would be eliminated by processes of selection in any event.

In conclusion, it may be stated with some assurance that the lizard population of Bikini, as represented during the 1947 resurvey, exhibited no material effects attributable to Tests A and B.

Studies at Bishop Museum and the University of Hawaii made upon the return trip from Bikini enabled Dr. Myers to identify three of the Bikini lizards as follows:

Large gecko-------*Gehyra oceanica*
Small gecko-------*Lepidodactylus lugubris*
Striped skink-----either *Emoia cyanura* or *E. werneri*

3.010 Reef and Lagoon Algae at Bikini

Studies of algae in and about Bikini Lagoon were concerned primarily with normal and abnormal physiology (including reproduction) and morphology, special attention being given to the possibility of detecting anomalies traceable to radiation effects. Attention was directed to algae because they are a primary element in the food chain of the Bikini community, and in reef-building processes; and because -- especially in some localities -- algae are known to have come in contact with radiologically contaminated water and sediments. Some attention also was given to the problem of why some algae are calcareous. Structural studies were carried out by Dr. G. M. Smith, physiological studies by Dr. L. R. Blinks and Dr. P. M. Brooks, and biochemical analyses and measurements by Dr. W. A. Gortner.

Studies of algae made prior to Tests A and B in 1946 were largely taxonomic in nature, and the distribution of various species in the Bikini area was not well-mapped at the time. From the standpoint of blast effect and radiology, therefore, the best opportunity for obtaining significant resurvey data was through comparison of algae from radiologically uncontaminated areas with algae from areas known to have been contaminated, although the situation as a whole was further complicated by the fact that oil contamination and pollution had become important factors in the marine community.

Field observations of algae were conducted in various localities known to have been radiologically contaminated, and in normal situations as well. The localities represented included the seaward and lagoon shallow-water areas of Bikini, Uku, Bokon and Enyu Islands, and certain areas at Kwajalein and Rongerik. Examinations of algal growths on coral heads and at deeper levels in Bikini Lagoon were made possible by use of shallow-water diving gear. All of these field examinations were concerned with such matters as zonation (especially any interruption of growth), evidences of injury such as burning or bleaching, pigmentation in general, size, and the presence or absence of visible anomalies.

Algae from all localities studied were placed in containers brought back to the Experimental Biology Laboratory on Bikini Island (see Section 2.006). Here, in addition to regular chemical and biochemical supplies, microscopes, salt-water aquaria, and standard glassware, a spectrophotometer was available for examination of pigments, and apparatus had been provided for the measurement of differential light penetration, photosynthetic processes, and bioelectrical studies of single cells. Studies of calcium deposition, permeability, and respiration were also made. In addition, laboratory examinations and studies were conducted on algae brought up from the intertidal zone by members of various other Scientific Groups.

The findings here reported are relatively complete; however, some further research will be concluded at Stanford University and at Hopkins Marine Station by Dr. Smith and Dr. Blinks, which will be concerned with potassium determinations, verification of species identifications made in the field, and sectioning of specimens in a search for cellular anomalies. If any significant additional

facts are revealed it is understood that they will be reported to the Chief of the Armed Forces Special Weapons Project, although no formal arrangements for a supplementary report have been made.

One series of studies on algae growing in Bikini waters was concerned specifically with the following subjects: (a) effects of radiation from radioactive substances upon the abundance of seaweeds or algae; (b) effects of such radiation on the distribution of different species of algae; (c) changes in structure of seaweeds ascribable to effects of radioactivity; and (d) effects of radioactivity upon reproduction.

In addition, records were kept and specimens preserved of all algae collected, to make precise identification of the different species that are present in the Bikini Atoll Area. This phase of the investigation could not be completed until after return to the United States where adequate library and herbarium facilities are available.

Effects of radiation upon abundance. In comparison with the Pacific Coast of North America or the shores of the Hawaiian Islands, algae are far less abundant at Bikini. This fact, however, cannot be ascribed to radiation effects, because the abundance of algae at Bikini is fully as great as that found at the neighboring radiologically uncontaminated Rongerik Atoll.

At Bikini seaweeds (algae) are not equally abundant on the various islands of the atoll. Furthermore, as at Bikini Island, abundance along the inner and outer reefs is not uniform, and there are localized areas where algae occur in great profusion. To cite specific examples, on the outer reef of Bikini Island, algae are most abundant on the relatively radioactive portion external to the spit at the north end of the island, whereas, on the lagoon side, they are most numerous on the slightly contaminated reef about 1,000 yd. southeast of the spit at the north end of the island.

From this, and from study of other islands of the atoll, the conclusion may be drawn that there is no correlation between existing radiation intensities and localized abundance of seaweeds.

Effects of radiation upon different species. Irrespective of whether relatively scarce or abundant, the distribution of species is not uniform in any given area. On the outer reef, some types are found only close to the shore, other species are restricted to the outer edge of the reef, and still other varieties grow in the area midway between the outer and inner edges of the reef. Special attention was given to the distribution of the different species of algae growing on the portion of the outer reef external to the spit at the northwest end of Bikini Island, because this area is radiologically contaminated from the inner to the outer edge of the reef. The distribution of the different seaweeds at this spot is shown in figure 25. Although the total number of seaweeds on the outer reef along the uncontaminated south end of Bikini Island is considerably smaller, the different kinds present, and their local distribution, is much the same as on the contaminated northern reef.

The foregoing fact indicates that any existing localized distribution of seaweeds is not ascribable to high radiation intensities. At Bikini, as elsewhere throughout the world, localization of specific seaweeds in a definite portion in the intertidal zone is due to the interaction of a number of environmental (ecological) factors. It is beyond the province of this survey to consider this phenomenon, but it might be indicated that factors influencing distribution include ability to withstand desiccation when exposed to air by recession of the

tide, ability to withstand pounding of surf, ability to withstand high temperatures when the tide is out, the temperature of water currents, the degree of aeration of the water, the depth at high tide and the resultant effect on quantity and quality of illumination, and the physical nature of the bottom.

Radiation and morphological changes. Radiation may affect growth or algae in the following ways: (a) it may cause a slowing down of the rate of growth; (b) it may injure the entire plant, or may injure only the growing region which is more delicate than other parts of the plant; (c) it may modify the growing region so that subsequently produced portions differ in shape and structure from previously produced portions.

Explanation of Symbols; figure 28.

Ac	*Acetabularia*
Av	*Avrainvillea*
Ca	*Caulerba*
Cl	*Cladophora*
D	*Dictyosphaeria*
H	*Halimeda discoidea*
Hm	*Halimeda monile*
Htr	*Halimeda tridens*
Htu	*Halimeda tuna*
J	*Jania*
La	*Laurencia*
Li	*Liagora*
Ly	*Lyngbya*
M	*Microdictyon*
P	*Pocockiella*
T	*Turbinaria*
U	*Udotea*
Va	*Valonia aegagropila*
Vf	*Valonia forbesii*
Vu	*Valonia utricularis*

Note 1: When an alga grows under rocks, the symbol is enclosed by a circle (as U); when it grows on sides of rocks, the symbol is put between two parallel lines (as U); and when it grows on top of rocks, or the reef, the symbol is not enclosed (as U).

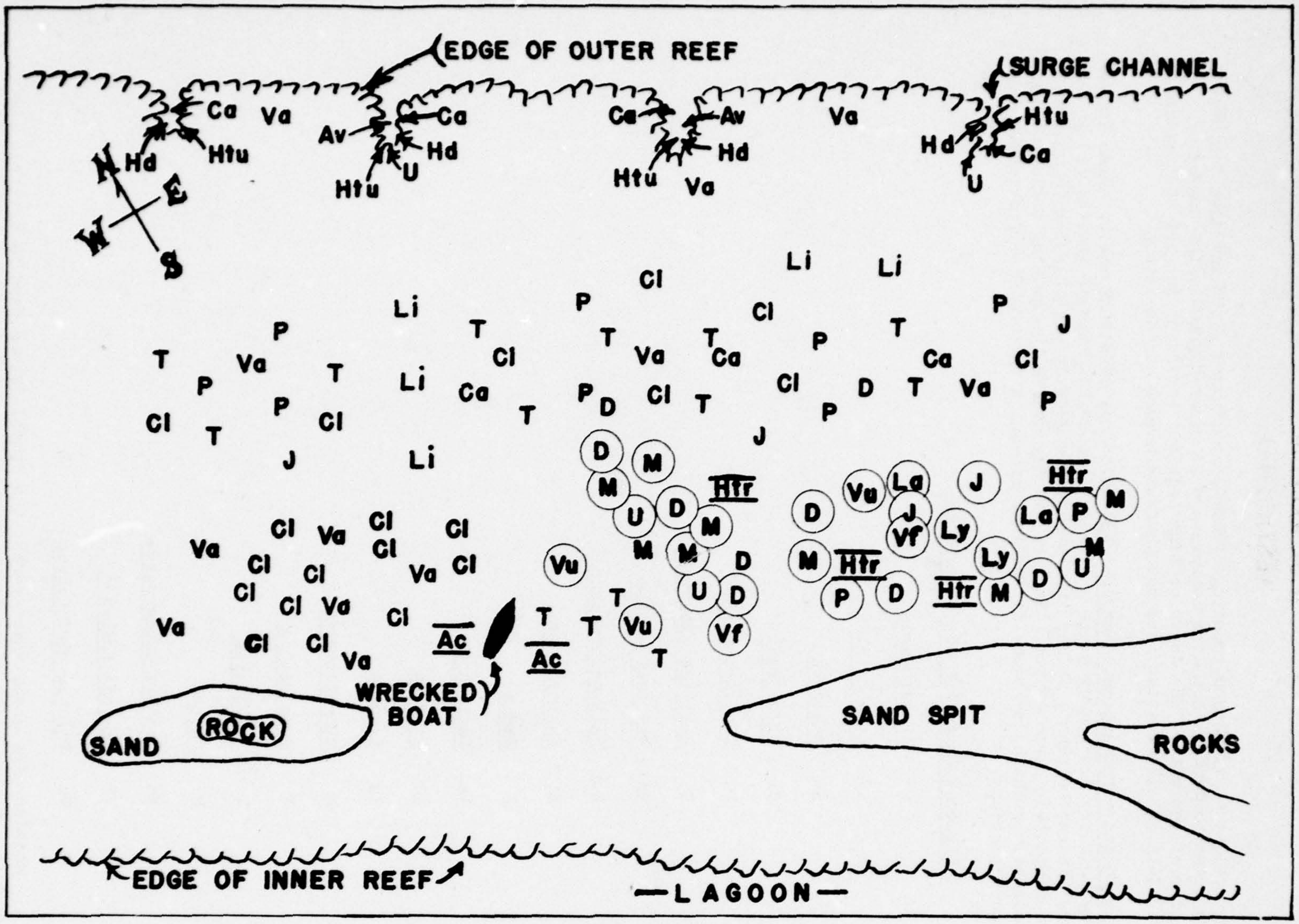

Figure 28. Diagram showing the distribution of algae at the northwest end of Bikini Island, as seen at low tide. Meanings of symbols are given on the following page.

Note 2: No attempt has been made to draw this map to scale, or to make the proportions accurate.

The green alga Udotea was selected for study of points (a) and (b) listed above. Udotea is a fan-shaped plant, in which the growth is localized at the upper margin of the fan. The mature portion downward from the growing margin is differentiated into a succession of convexly curved zones, each parallel to the growing margin. A radiation effect upon growth of this plant might result in either of the following: (a) a slowing down of the rate of growth might result in the later-formed zones being narrower than the earlier-formed ones; or (b) a killing of localized portions of the growing margin would result in an interrupted fan in which certain sectors had continued growth and others had not. No evidence of either eventuality was found in the hundreds of plants examined.

Growth of plants usually is by division and subsequent enlargement of the units of structure -- the cells. Radiation may affect a cell so that cells formed by or from it differ in appearance from the original cell. The best place for finding atypical results among algae would be in those blade-like plants in which all growth is initiated by a single cell at the apical tip of a blade. Radiological modification of the nature of such a single cell would result in a blade with the upper portion differing from the lower portion. Two seaweeds found at Bikini have blades with a single apical cell. Hundreds of specimens of one (Dictyota) were collected, but only a dozen of the other (Caloglossa) were found. In neither of the two was there any evidence of structural abnormality in the upper part of the plant.

Effects of radiation upon reproduction. Reproduction of seaweeds may be sexual, represented by a liberation of two sex cells that fuse to form a single cell which develops into a new plant. Or, reproduction may be non-sexual, represented by liberation of a special cell which does not fuse with another cell before developing into a new plant. Reproduction of some seaweeds found at Bikini is known to be by both methods; that of other Bikini seaweed is known to be either exclusively non-sexual.

Some of the seaweeds collected at Bikini Atoll were producing sexual or non-sexual reproductive cells, but a majority of the species were not. There are two alternative interpretations of the species not producing reproductive bodies: (a) they are sterile as a result of radiation; or (b) they are in a normal non-fertile condition, and are potentially capable of becoming fertile. The second alternative is here considered much more probable. Reasons for this conclusion include the well-known fact that many seaweeds found in other parts of the world are only fertile at certain times of the year. Furthermore, study of the seaweeds collected during a brief visit at Rongerik Atoll suggests that the percentage of fertile species at this radiologically uncontaminated atoll is approximately the same as at Bikini.

In every case where sexual and non-sexual reproductive organs of Bikini seaweeds were examined microscopically, they appeared normal in all respects.

Radioactive Material in Algae. Radiological surveys indicated that the northwestern spit of Bikini (A in fig. 29) and the adjacent coral heads (A_1) just within the lagoon were the most radioactive regions readily available for the collection of living algae, while the easterly reef (B) and southern spit (C) of this island were relatively free from radiological contamination. The lagoon reef (D) also was used to some extent. These areas were visited frequently for purposes of observation and obtaining samples, collected algae being brought in quickly, with care being taken to provide aeration and prevent warming. The specimens were used

immediately or kept in running sea water for use on later days when necessary. Certain forms lived well: Caladophora, Valonia, Dictyosphaeria, Microdictyon, Turbinaria, Halimeda, Lyngbya, Avrailvillea, Jania, Caulerpa cupressoides. Others, including Udotea, Liagora, Caulerpa racemosa, and Halimeda tuna were very sensitive, and could scarcely stand transport from the reef. (H. tuna appeared to be dying on all the reefs; doubtless a seasonal effect).

Study was made of at least one red, brown, and blue-green form, as well as several green algae, from normal and radioactive regions: calcareous forms were also included when possible.

Among the physiological activities studied were: permeability, salt accumulation, bio-electric potential, pigment content, photosynthesis and respiration, enzyme activity and calcification. Many of these phenomena are known to be sensitive to other radiations such as ultra-violet, infra red, and X-Ray; as well as to poisons and higher temperature. It was thought that one or more processes might be altered by the radioactivity of fission products that were in or around the algal cells.

Field measurements made this year on the algae themselves indicated only a low degree of radioactivity, scarcely above background in the majority of cases, even when the plants grew on fairly radioactive rocks or sand. There evidently is little accumulation of radioactive fission products by the algae; this is consistent with the fact that most algae do not concentrate the heavier elements to any great degree (although K and I are accumulated to some extent). Exceptions to this statement occur chiefly in the case of Halimeda, which exhibited counting rates as high as three or four times background, even when well washed of adhering sand and silt. Clumps of Cladophora or Valonia (in pin-cushion form) often yielded fairly high counting rates, which however, dropped to low levels when the cells were washed free of adhering sand and silt. Most other algae showed none.

In view of this low actual accumulation of radioactive material within the plant tissues, attention became focused on the possible effects of external radiation, from the substrata, or from silt, etc., on the surface of cells. In many cases, this external material produced beta and gamma readings of from 0.001 r/24 hr. or 0.002 r/24 to 0.01 r/24 hr. or even 0.06 r/24 hr, the latter in the case of rocks from the most radioactive coral head (A_1) investigated. The actual dosage-rate was much greater, as shown by the increased reading when the algae mass was removed from between the source material and the meter. While fairly low at the time of the resurvey, the radiation intensity was much greater during the previous year. Any lasting effects of more intense radiation might therefore show up in alterations of function.

Physiology of Bikini Algae. Cellular permeability and salt accumulation frequently are very sensitive indicators of injury. Valonia is a genus often used for such studies, and it occurs on the north point of Bikini Island, where moderate radiation bombarded the cells constantly. Normally, a high K content and absence of sulfate in the cell sap prevail; if injury had occurred, potassium chloride would have diffused out and sulfate would have entered. However no sulfate could be detected, and the K content was qualitatively high (quantitative analyses will be performed in the United States).

Dyes such as methylene blue and cresyl blue entered the cells of Valonia and Dictyosphaeria, and became accumulated in the cell gap equally well in normal and in irradiated specimens. Also, the cells of Microdictyon (both normal and irradiated) showed continued shrinkage (plasmolysis) with 1 M glycerol added to sea water; while they both recovered within a few minutes after shrinking in ethylene

glycol. This behavior indicated normal permeability to both water and non-electrolytes. Evidently there had been no disturbance of this sensitive function.

The closely related bio-electric potential also was measured across the protoplasm of Valonia Forbesii (the cells of which reach diameters of 1 cm or more); it was found to have the normal value (about 15 millivolts, outside negative) in cells collected both from stations A and B (radioactive and normal). The normal plastid pigments (chlorophyll, carotenoids and phycobilins) of algae frequently are very sensitive to injury, and change both in absolute and relative amounts due to irradiation, temperature change, or inorganic nutrition lack (especially iron deficiency). It was of great interest to see whether the Bikini algae were altered in any way, in their pigment complex. Extracts of weighed pieces of algae were made with methyl alcohol, and the absorption spectra determined in the Beckman spectro-photometer. Chromatographic separation of the pigments on sucrose or starch columns also was carried out. In neither green, brown, nor red algae was any alteration of pigment component ratios found which could be acribed to irradiation by fission products. Much greater dependence on solar radiation was found. Algae exposed to intense sunlight showed bleaching or yellowing of the upper parts -- this was especially true of Laurencia and Lynbya (a red, and blue-green alga, respectively). To determine whether the absolute amounts of the major pigment (chlorophyll) were altered, transmission percentage was read at the red absorption maximum (663 mu). The values varied greatly from alga to alga on a dry weight basis, but no consistent trend could be found between plants from normal and radioactive regions. Cladophora collected from station A did seem to have about twice as much chlorophyll as samples from station B; this difference, however, may be ecological rather than radiological in origin, since the plants in question grow on much more exposed rocks and form denser cushions. Some nine other genera also were studied, including red, brown and green algae; no others showed this trend. As many exhibited increase as exhibited decrease, and numerous types were nearly identical or within the normal variation.

In view of the absence of radiation effects upon the chief photosynthetic pigment, it was of interest to study the overall photosynthetic rate. This was done by measuring oxygen production, determined in solution in sea water by the Winkler method. The plants usually were put in 250 cc flasks in a water bath over fluorescent lamps of an intensity about 200 foot candles (1/4 or 1/5 that of direct sunlight). Exposures of 1 hr. to 6 hr. were given, the latter usually being sufficient to saturate the sea water with oxygen. Rates were reduced to a common basis of cc O_2 gm/hr. wet weight of tissue. Values ran from 0.06 cc gm/hr. (Valonia) to 0.76 cc gm/hr. (Bryopsis), many algae showing about 0.1 cc gm/hr.

No evidence of a trend in either direction could be detected. The number of cases of a higher rate in normal plants was balanced by the number of cases showing higher rate in irradiated plants, and the differences fell well within the range of variation. Since photosynthesis is a complex process involving many successive energy absorptions and enzyme reactions, an injury at any stage should be reflected in a lower rate. No clear case of such effect was found. Evidently those plants which survive at all had an essentially normal photosynthesis mechanism.

Respiratory rate also was measured, for comparison with photosynthesis, and in order to make proper corrections for the latter. The method was the same, except for keeping the plants dark. Rates between 0.0075 cc/gm/hr. and 0.03 cc/gm/hr. were found in different algae, but as in the case of photosynthesis,

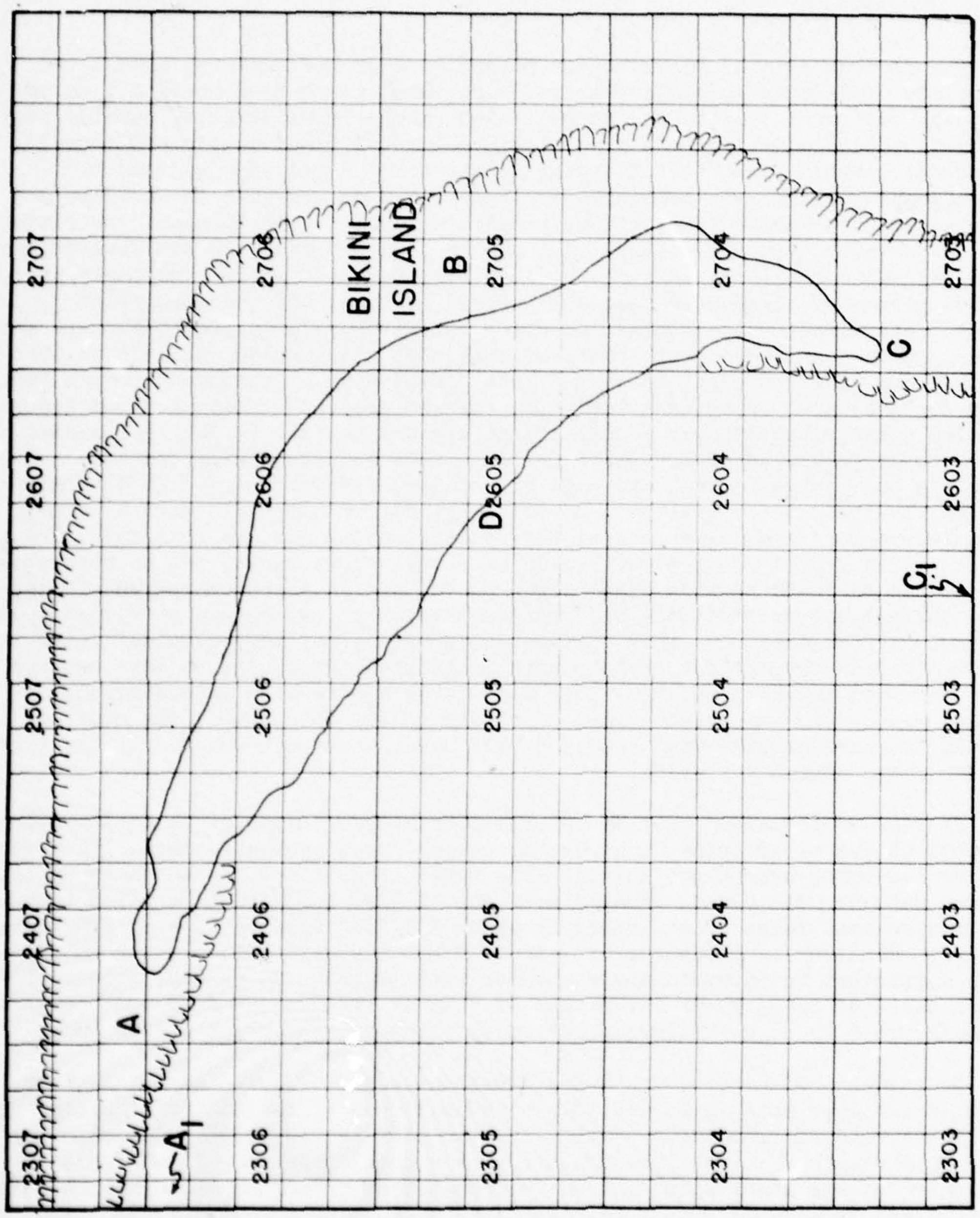

Figure 29. Collecting stations for algae; Bikini Island.

Alga	From Radioactive Region		From Non-radioactive Region		
Avrainvillea		.056 .126	.11		
Caulerpa		.36 .05 .025 .018	.100 .154 .115 .02		
Cladophora		.04-.08 .06-.12	.10		
Dictyosphaeria		.071 .10 .127	.11 .11 .066		
Halimeda	.057 .108 .056 .049	.14 .101 .07	.066 .044 .038	.12 .036 .05	.03 .066
Laurencia	.108		.01-.02 .13 .077		
Microdictyn	.186 .143	.26 .173	.275 .28	.19	
Pocockiella		.196	.16		
Turbinaria		.07	.057		
Udotea	0.4 0.225	.01 .178	.365 .22		
Valonia		.07	.06		

Table VI. Photosynthesis of Bikini algae. Rates given in cc of O_2 gm/hr.

no consistent difference could be found between plants from radioactive and non-radioactive areas.

Oxidative enzymes (oxidase and peroxidase) showed great variation among different genera of plants, but exhibited no effect ascribable to radiation.

The latter statement was not true, however, of the enzyme catalase (which decomposes hydrogen peroxide, yielding gaseous oxygen). In at least three genera (Halimeda, Udotea and Cladophora) the release of oxygen by this enzyme was at a consistently higher rate in plants obtained from area A than in plants from area B. In Halimeda, this ratio was 2 to 6-fold, averaging 3.7. In the two other genera it was at least 2-fold. (Laurencia and Turbinara showed a smaller difference). It is noteworthy that the three genera with the higher catalase activity were those exposed to the highest radiation intensity, or those which showed highest fission-product accumulation. No clear explanation is at hand for this effect, but the suggestion is made that it is an "adaptive enzyme" response much like that recognized in other cases where a substrate change is made. It is known that hydrogen peroxide is formed by X-Ray and other radiations in water. It seems possible that something of a similar nature may have occurred in these plants, the enzyme increasing in concentration to parallel the extra H_2O_2 (which is toxic). Another possibility is that a "micro-nutrient" necessary for the elaboration of catalase was provided among the fission products (whether radioactive or not); the role of elements in small traces in other plants suggests this. The direct catalytic effect of such metals was ruled out, since most of the catalese activity was destroyed on boiling; this fact indicates enzymic character.

Calcification is an important aspect of certain tropical algae, notably the red "corallines" of the reef edge, and also several green genera. The percentage of calcium carbonate was determined for various Bikini algae as follows:

PER CENT $CaCO_3$ (dry weight)	
Halimeda tridens	65-66
H. monile	68-69
H. sp (deep water, 250 ft)	76
Udotea	54
Neomeris	69
Jania	57
Liagora (1)	54
Liagora (2)	69
Padina	40

No significant difference in the percentage of calcium carbonate was found in Halimeda tridens collected from radioactive region A.

It is not known why some algae are calcified, while closely related and ecologically adjacent genera are not. An attempt was made to investigate this problem, using three green algae which were fairly closely related, of similar size,

and all growing on the same rocks of station D. The photosynthetic rate (O_2 production) in two series was compared under equal illumination (200 foot candles), with the following results:

O_2 EVOLUTION (cc/gm/hr)

Series	Bryopsis	Caulerpa	Halimeda
1	0.73	0.154	0.031
2	0.265	0.115	0.066

The calcified genus Halimeda obviously showed the lowest photosynthetic rate, even when allowance was made for its smaller percentage or protoplasm. The highest rate occurred in Bryopsis, which exhibits no calcification. Thus, lime disposition hardly can be due to more rapid utilization of CO_2 and rise of alkalinity in the vicinity of the calcareous forms. Some special mechanism may be involved, such as very closely appressed cells, which hinder diffusion, or a proper crystalline structure of the cell wall which "seeds" the deposition of calcite or aragonite. (Deep water Halimeda showed the highest calcification, which again could hardly be due to high photosynthetic rate, the light intensity being very low at 250 ft).

Identification of radioactive elements was attempted in samples of Halimeda collected on a dead coral head, (A_1). This head was in the direct path of the bomb surge wave, and was killed either by radioactivity, high temperature, or silting. Some young coral colonies, and many young algae, were re-establishing themselves, (though only in patches). These algae included Halimeda, Udotea, Caulerpa, Avrainvillea, Microdictyon and Pocockiella. The older Halimedas were covered with silt and epiphytes, indicating poor condition of the plants.

The coral and rocks yielded beta-gamma readings ranging from 0.005 r/24 hr. to 0.06 r/24 hr, averaging 0.02 to 0.03 r/24 hr. Such high persistive activity suggests that there was high radiation intensity just after the blast -- possibly 100 to 1,000 times the values cited.

Halimeda growing upon these rocks registered intensities of 0.005 to 0.01 r/24 hr. About 400 gm of the algae were decalcified with HCl; then washed well with water, which removed loose insoluble residues, wpiphytes, etc. The acid solution was filtered; then precipitated with ammonia which threw down iron hydroxide and absorbed substances. After filtration, the solution was dried. The four fractions were monitored for radioactivity, which ran as follows:

1. Decalcified plants (cellulose, etc.) - 0.01 r/24 hr.
2. NH_4OH precipitate ($Fe(OH)_3$, etc.)- - - 0.02 r/24 hr.
3. Suspended matter (debris, epiphytes) - 0.03 r/24 hr.
4. Soluble fraction (filtrate)- - - - - - 0.00 r/24 hr.

The first three were then submitted to the Radiochemical Laboratory, which reported the following counting rates: 452 c/min; 951 c/min; 6,120 c/min.

The "Sterile Region" at North Spit. When the northwestern point of Bikini was first investigated by us, we were impressed by the complete absence of any algae on and around the wreckage of a small boat at that point. Neither the plants, rocks upon the ribs, nor rocks within 10 ft. supported an algal growth

of any size, if at all. Gradually more growth appeared at a 20 to 30 ft. distance, and was normal slightly beyond this distance. This was suggestive of radioactive injury and the wreck was monitored with caution. However, it showed no radioactivity above background. Evidently the injury to algal growth was of some other sort -- possibly a gasoline fire, or oil, or metallic contamination. It may be concluded, however, that algal growth in the region is comparatively slow -- there had been no recolonization on the boar or nearby rocks. This gives good evidence on the absence of injury by the bomb and later events over the rest of the region. For if there had been mass killing, recolonization might not have occurred yet. This wreck should be carefully inspected if another resurvey occurs, to map recolonization.

Light penetration studies were undertaken with apparatus loaned by Dr. G. L. Clarke of Harvard University. The results are shown in fig. 30 and fig. 31. Rongerik exhibited the clearest water tested (though one Bikini reading at station A was about the same). This was well toward the clarity of open tropical ocean water. Kwajalein (inside reefs some miles from docks) approached coastal water values, and one Bikini reading (station C_1) was within the latter values. These figures doubtless would vary from place to place and from day to day, but they may have interest in showing whether turbidity is abnormally high since Test B, and how deep algae could live.

The spectral distribution shown in fig. 31, indicates greatest penetration of the blue region. This suggests the relative absence of microscopic algae, which tend to favor the penetration of green light (in coastal waters). Therefore, the turbidity of Bikini lagoon probably is due to calcareous silt, rather than phyto-plankton.

Conclusions. The algae now surviving at the most accessible radioactive spot (northwest spit of Bikini Island) are abundant, and like those of other, normal regions, both in appearance and in a variety of vital functions which were measured. The catalase activity of two genera from radioactive areas was markedly enhanced, possible as a response to hydrogen peroxide produced by radiation. If extensive damage or killing occurred at Bikini last year, this has been largely repaired by new growth; but it is doubtful that such restoration could be effected so rapidly. Our conclusion is that the marine algae are remarkably resistant to the effects of the bomb. Probably many of them were killed on submerged coral heads near the site of the explosion, but recovery is occurring.

Moreover, all available data indicate that radiation effects have not reduced the algal population of Bikini Atoll, or produced a change in the distribution of the various species. No evidences of morphological changes due to radiation were discovered, and there was no indication that fertility had been impaired.

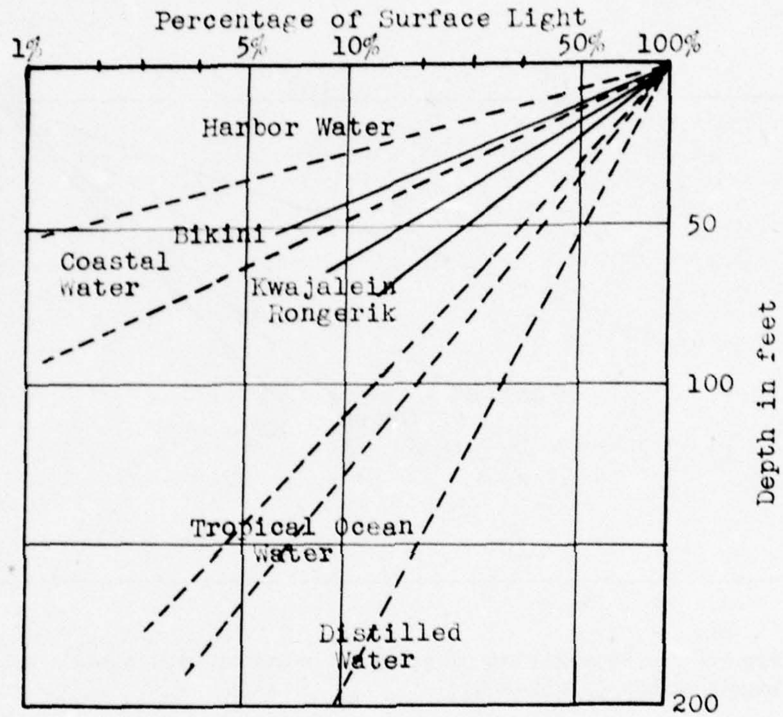

Figure 30. Penetration of "white" light into various sea waters.

(Dotted lines from G. L. Clarke, Harvard University)

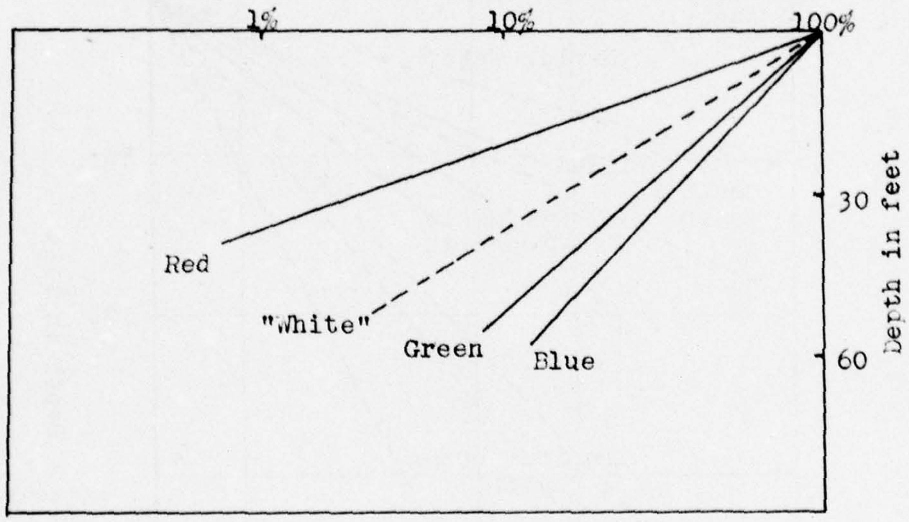

Figure 31. Penetration of spectral regions into Bikini Lagoon water (station C_1).

(Note: "White" is really the overall response of the Western photronic cell, which is most sensitive to the yellow-green.)

Figure 32. Dr. L. R. Blinks making physiological tests on algae in an Experimental Biology Laboratory on Bikini Island. ABCR Photo No. 5041-4.

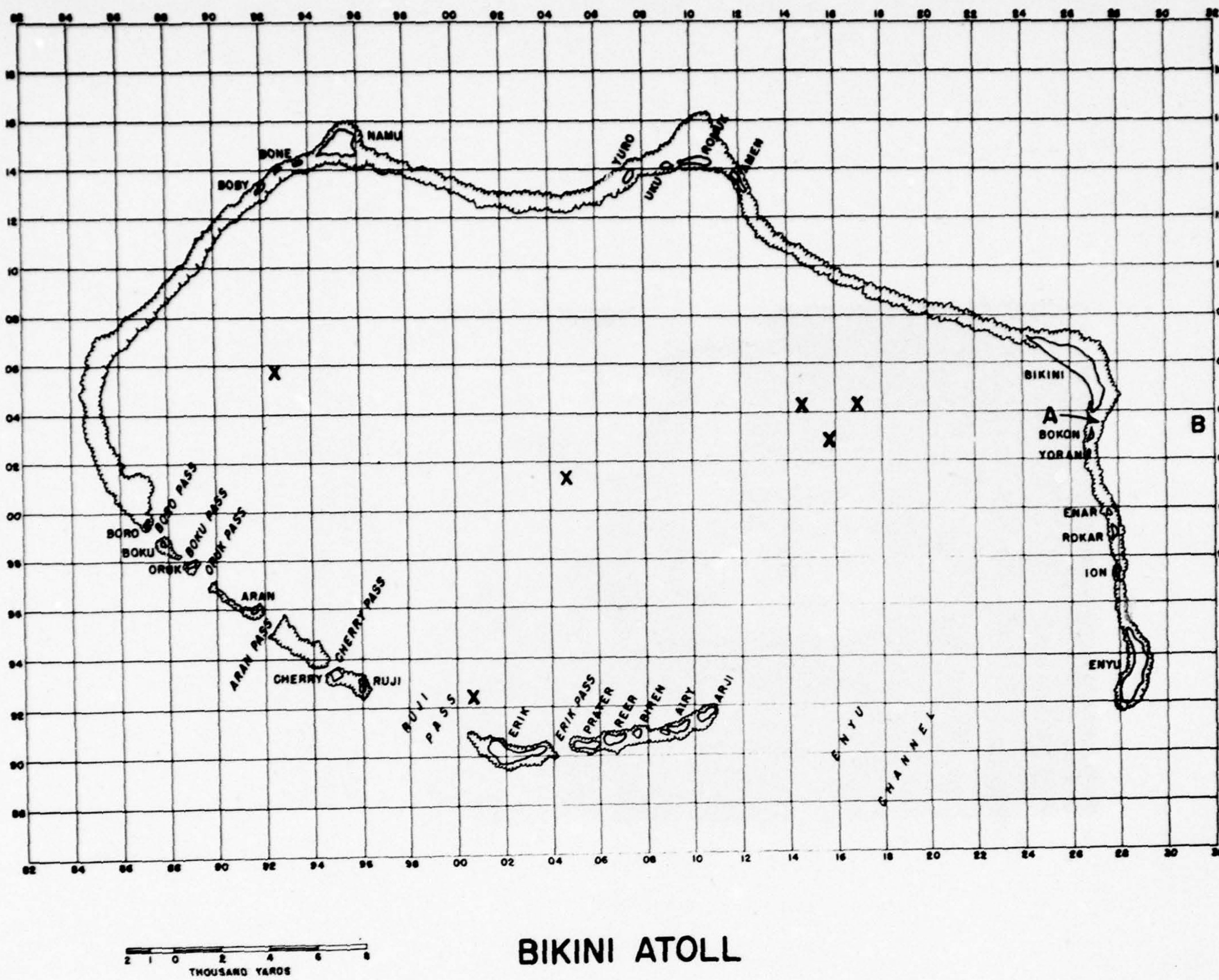

Figure 33. Stations where samples were taken to study the chemical effects of organisms upon sea water.

3.011 <u>Chemical Effects of Organisms Upon Sea Water</u>

Studies concerned with the chemical effects of organisms upon sea water were carried out by way of supplementing information concerning ecological conditions in Bikini Lagoon and along selected bordering reefs. The primary purpose of these studies was three-fold: namely, (a) to obtain data related to the yearly growth increment of the reef, (b) to determine, if possible, the cause or causes of the apparently abnormal opacity of the waters at the eastern end of the lagoon, and, (c) to improve the rather limited knowledge concerning diurnal chemical changes in tide pools. These studies were begun by Mr. T. F. Goreau, and carried on during the last two weeks of the resurvey by Mr. T. S. Austin. During the entire period of the study, a PhM3 from <u>Chilton</u> (APA-38) provided capable assistance.

A mobile laboratory was set up on Bikini Island, as described in Section 2.006, for the purposes indicated. It was equipped with the chemical gear necessary for routine marine ecological studies, including oxygen-titrating apparatus (Winkler method), a bicolorimeter, and nitrate determining apparatus.

The above-mentioned mobile laboratory was moved to the site of the reef studies, the reef extending between Bikini and Bokon Islands, and designated as A in figure 33. As oceanic water flows <u>into</u> the lagoon continuously over the eastern and northern reefs, the site chosen was one of the most suitable for the desired studies. The reef is covered with varying amounts of coral, algae and other marine organisms. During daylight hours it may be assumed that various types of marine plant life are carrying on photosynthesis, utilizing carbon dioxide, and the nutrient phosphate and nitrate salts from the water, and at the same time evolving oxygen. All organisms continually discharge their metabolic waste products into the water during daylight hours; while during the hours of darkness, photosynthesis essentially ceases and katabolic processes of marine organisms which utilize oxygen and discharge carbon dioxide are paramount.

To test the effects of such organic processes upon the sea water entering the lagoon, three types of samples were collected, as follows:

A. Samples were taken along a line extending from the surf zone to the lagoon side of the reef, at a point approximately midway between Bikini and Bokon Islands. These samples, plus depth, temperature and current velocity measurements, were taken every three hours, tide permitting, during several 48 hour intervals.

B. Samples taken from a series of tide pools, where the concentration of organisms in a comparatively small volume of water could be expected to produce marked changes. Four pools, or solution basins, were selected. Two were completely flushed by high tide, one partially flushed, and one usually isolated from the oceanic circulation during the neap tide period.

C. One series of samples was taken in the open ocean, approximately five miles seaward from the southern tip of Bikini Island (B, figure 33). The data obtained from analyses of these samples ultimately will be compared with data concerning samples A and B.

During the period of the 1946 survey, prior to Test B, the lagoon waters were very transparent. The bottom could be seen at depths in excess of 100 ft. This, however, was not entirely true during the 1947 resurvey. Some factor, or factors, resulted in a considerable decrease in the transparency of the lagoon waters

(as measured by a Secchi Disk: a circular plate, 30 cm in diameter, painted white). Several hypotheses have been advanced as to the cause of this decrease in transparency. These include (a) the presence of finely divided particles of calcareous material suspended in the water, (b) seasonal fluctuations resulting from a wind shift (westerly to southerly) and the swells of southern origin entering Enyu Channel, and (c) an increase in organic productivity, resulting in a greater number of planktonic organism per unit volume of water.

In an effort to ascertain the cause or causes of the decrease in transparency, the following tests were conducted:

A. Surface and bottom water samples were taken in Nansen bottles at various locations in Bikini Lagoon (see fig. 33). These samples were analyzed for oxygen, pH, and alkalinity. As the bicolorimeter was inoperative, and as the phosphate apparatus did not arrive from the United States in time, nitrate and phosphate analyses were not conducted. Data resulting from the analysis of these samples, in conjunction with that obtained from biochemical oxygen demand and bacteriological tests, and the plankton hauls, will give a basis for estimate of the present organic productivity in Bikini Lagoon. The data may then be compared with 1946 results.

B. Samples of water were taken at the surface, at 40 meters, and at 400 meters at one oceanic station about 5 miles seaward from the southern tip of Bikini Island. Data from this station will be used as a control, and for comparison with the data concerning reef and lagoon samples.

A portion of each of the samples mentioned above was preserved for eventual shipment to the Scripps Institution of Oceanography, where final analyses of calcium content and salinity values will be arrived at by direct measurement. Such measurement could not be effected at the resurvey site because it requires special apparatus that was not available. Data coming from these final tests, plus evaluation of all other data, and conclusions drawn, will be submitted in a report to the Chief of the Armed Forces Special Weapons Project about 5 to 6 months from date.

Meanwhile, it may be indicated that the decrease in water transparency noted in Bikini Lagoon is a relatively localized phenomenon. When compared with 1946 observations, the western half of the lagoon appears to be normal. Secchi disk readings in the target area and east of the target area averaged 32 ft, while those taken west of the target area ranged from 70 ft. to 80 ft. Considering the presence of finely divided sediments in the target area and the swells entering Enyu Channel accompanied by SE or E wind, it seems possible that the above-mentioned opacity of waters is a transient and purely physical feature. However, further evaluation of samples collected may alter this conclusion.

3.012 The Insect Population of Bikini

Extensive insect collections were made on Bikini, Enyu, Prayer, Rokar, and Namu Islands by Dr. A. C. Cole. The purpose of these collections and associated taxonomic studies was to determine, insofar as possible, the insect population of Bikini Atoll, as a part of the overall biological community, and to investigate the existence of any structural anomalies. Insects were found to be represented on all of the islands, despite the fact that Bikini Atoll had been dusted with DDT prior to arrival of Task Group 10.12. Unfortunately, no population studies of insects were made prior to the Operation Crossroads tests, so no real basis existed for post-test comparisons, although in any event the findings would have been obscured by use of the DDT.

In making collections, ordinary entomological gear was employed, including collecting nets, killing bottles, aspirators, and containers. All specimens were brought back to Chilton (APA-38), where field identifications were effected. The specimens were then packaged for eventual shipment to the United States, where accurate identification of species and more critical studies of morphology will be concluded. Some living specimens of Drosophila were also returned to the United States, in the prospect that they might serve as the basis for continuing genetic studies. A final report on the entire investigation will be prepared by Dr. Cole at the University of Tennessee, species determinations being checked by specialists on the various groups represented. At present, no plans have been made for publication of the final report, but it will be made available to the Chief of the Armed Forces Special Weapons Project.

More insects, both quantitatively and qualitatively, were found on Bikini Island than on the other islands, although they were not a conspicuous element of the fauna in any locality. The existing difference in population was not believed to be correlated with any radiation effects, but rather with the fact that Bikini Island supports an extensive growth of vegetation, and boasted a human settlement prior to Operation Crossroads. The presence of man tends to favor the introduction and multiplication of various insect types. At the present time, there is no way in which the normal, endemic insect population of Bikini Atoll may be ascertained.

Orders of insects represented on the islands inspected are much the same. Termites (Order Isoptera), however, were found only on Bikini Island. Otherwise, representatives of the following orders and families were collected:

A. Order Orthoptera

 1. Family Blattidae (cockroaches): abundant
 2. Family Gryllidae (crickets): moderately abundant

B. Order Isoptera (termites): scarce

C. Order Odonata (dragon flies, etc.): rare

D. Order Mallophaga (biting lice): abundant on some birds

E. Order Hemiptera

 1. Family Pentatomidae (stink bugs): moderately abundant
 2. Family Myridae (plant bugs): scarce
 3. Family Cicadellidae (leaf hoppers): abundant
 4. Family Gerridae (water striders): scarce

F. Order Thysanoptera (thrips): scarce

G. Order Neuroptera

 1. Family Chrysopidae (lace-wing flies): abundant

H. Order Lepidoptera

 1. Family Sphingidae (hawk moths): abundant
 2. Family Noctuidae (owlet moths): abundant
 3. Family Hesperiidae (skippers): rare
 4. Family Nymphalidae (four-footed butterfiles): abundant

I. Order Diptera

1. Family Culicidae (mosquitoes): scarce
2. Family Muscidae (house flies, etc.): scarce
3. Family Metopiidae (flesh flies): rare
4. Family Drosophilidae (fruit flies): very abundant
5. Family Trupaneidae: scarce
6. Family Hippoboscidae (louse flies): scarce--found on terns
7. Family Chironomidae (midges): relatively uncommon
8. Family Sepsidae (shore flies): moderately abundant

J. Order Coleoptera

1. Family Coccinellidae (ladybird beetles): moderately abundant
2. Family Elateridae (click beetles): scarce

K. Order Hymenoptera

1. Family Ichneumonidae (ichneumon "flies"): moderately abundant
2. Family Formicidae (ants): moderately abundant
3. Family Vespidae (colonial wasps): scarce
4. Family Megachilidae (leaf-cutting and mason bees): moderately abundant
5. Family Evaniidae (ensign flies): abundant

All three species of butterflies recorded from the Marshall Islands (Hypolimnas bolina, Precis vellida bismorpiana, and Bahamia exclamations) were taken on Bikini and Enyu Islands; only a few individuals of the first-named species were found on Prayer Island, but both the first and the second species were collected on Namu.

Among the other arthropods found in the area were a few species of spiders, two species of scorpions, one species of centipede, and one species of millipede.

In summarizing studies of the insect population of Bikini Atoll the following conclusions may be noted:

A. The insect population might be termed "normal" for islands of this general area.

B. No structural anomalies were observed which might have been caused by blast or radiation effects. It is possible, of course, that continuing studies of Drosophila, taken in living form at Bikini, may reveal genetic abnormalities in excess of normal variability.

3.013 Marine Invertebrates at Bikini

This phase of the scientific investigation at Bikini was concerned with taxonomic and ecological studies of invertebrates, special attention being given to changes in population or in the morphology of species represented in the target area. Studies were made by Dr. J. P. E. Morrison and Mr. F. M. Bayer, the former having carried on a similar survey at Bikini during a six months period in 1946. This earlier survey provided a background study for comparison with 1947 results, and it might be said that the 1947 survey was for purposes of completing a comprehensive study of invertebrates at Bikini, and also to observe any differences between pre and post-Operation Crossroads data.

Dr. Morrison concentrated his attention upon the well-represented mollusk group, while Mr. Bayer placed particular emphasis upon the various species of crabs found on the coral reefs, and especially their natural coloration, the latter being an important factor in species identification. Other types of invertebrates were also studied, as time and opportunity allowed.

All of the ordinary methods of collection were used on and about the reefs, the only special gear employed for this purpose being collecting nets and containers for the specimens. Most of the Bikini reef collections were made on Bikini, Enyu, Prayer, Namu and Erik Islands, and some additional materials were obtained at Rongerik for purposes of comparison. Dredging gear was also used, to obtain specimens from the bottom, both within and without Bikini Lagoon.

All specimens taken were returned to the laboratories in Chilton (APA-38) (see Section 2.006) where identifications were completed insofar as possible, general examinations were made, and materials were packaged for shipment to the Smithsonian Institute, Washington, D. C.

In addition to the general data and conclusions listed in the following paragraphs, a final report dealing with invertebrates at Bikini will be prepared for publication at a future date. This report will be based upon identification of all species, and a comparison of the 1946 and 1947 data. Dr. Morrison will prepare the section of the report dealing with mollusks; and Mr. Fenner Chace (Curator of Marine Invertebrates) and Mr. Bayer will be responsible for the other marine invertebrates. It is presumed that the report, when completed, will be published either by the Smithsonian Institution or the Navy, but that in any event it will be made available to the Chief of the Armed Forces Special Weapons Project.

Mr. Bayer collected about 275 lots of specimens during the course of the resurvey representing the following groups: Protozoa, Porifera, Coelenterata, Platyhelminthes, Nemathelminthes, Annelida, Echinodermata, and Arthropoda. Collecting stations were located on Prayer, Enyu, Rokar and Namu Islands of Bikini Atoll, and on Latoback and Bock Islands of Rongerik Atoll. All invertebrates observed were found to be carrying on normal reproductive activities.

The only possible case of morphological changes observed was represented by a zanthid crab, Trapezia digitalis speciosa, which exhibited an aberrant color pattern. This crab was common on all islands of Bikini Atoll visited, and was found at the north end of Bikini Island in fully adult condition; in other localities only juvenile individuals were found. It was suggested that radiation may have caused a delay in the acquisition of adult color characters; that is, an abnormally extended juvenile (not larval) period. Although a careful search was made, this species of crab was not found at Rongerik. It should perhaps be noted that the genus Trapezia is quite variable as to morphology and color. An extensive series of these crabs was collected to supply material for continuing studies.

Dr. Morrison made an ecological and faunistic check on invertebrates at Bikini and at Rongerik. More than 100 lots or samples of mollusks (and other invertebrates) were secured to supplement the very extensive collections made in 1946. A complete re-examination of ecological relations of animals was carried out, including habitat observations on all ecological zones of Bikini Atoll. Included in the latter were the lithothamnion ridge of the outer reef edge: the outer and inner reef flats; the island shore-line zones, both inter-tidal and supra-tidal; the land areas, and the lagoon bottom.

Re-examination of the reef flats and shore-line zones revealed several species not previously known to belong to the Bikini molluscan fauna. All species observed and/or collected on the reefs by Dr. Morrison apparently were completely normal morphologically, and normal as to activities as well, insofar as this latter fact could be established by field observations. Young individuals in appropriate numbers were represented in the population, indicating that reproductory activities had not been affected adversely.

The lagoon bottom of Bikini Atoll apparently was normal faunistically with the following exceptions:

A. In the small area immediately around the site of the Test B explosion, the calcareous silt or "mud" (of the consistency of marl deposits) of the lagoon bottom was almost barren of mollusks (and other invertebrates). The few species of snails dredged from this area during August, 1947, were types possessing relatively rapid means of locomotion, rather than sedentary species, and might, therefore have been transients in the target area. Unfortunately, not enough is known concerning the physiology of these bottom dwelling animals to prove whether the silted condition of the bottom, or radioactivity, or both, caused the depopulated condition that was observed.

B. A wider zone surrounding the silted area (at least as sampled to the westward) exhibited a very much modified fauna. The characteristic corals of this area were represented by broken, dead fragments only, and living algae such as *Halimeda* were very scarce. One of the most characteristic shells found on this type of bottom in 1946 apparently was absent in 1947, although it had been abundant on this section of the lagoon bottom three weeks after Test B.

C. The "*Halimeda*" type of bottom deposit appeared to be normal at a distance of about a mile from the silted area, although the number of living *Halimeda* plants seemed to be below the normal level of abundance observed in 1946. This observation may, however, merely reflect seasonal differences, or spot-variation differences of the ecology of the bottom in the particular areas dredged in 1946 and 1947.

To summarize, it may be said that Dr. Morrison's observations and supplemental collections of specimens gave evidence that mollusks and other marine invertebrates of Bikini were morphologically and physiologically normal 13 months after Test B, except in the small area immediately around the Test B target center, which is largely depopulated.

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Figure 34. Dr. J.P.E. MORRISON of the U.S. National Museum in a collecting blind on Bikini Island. ABCR Photo No. 5102-12.

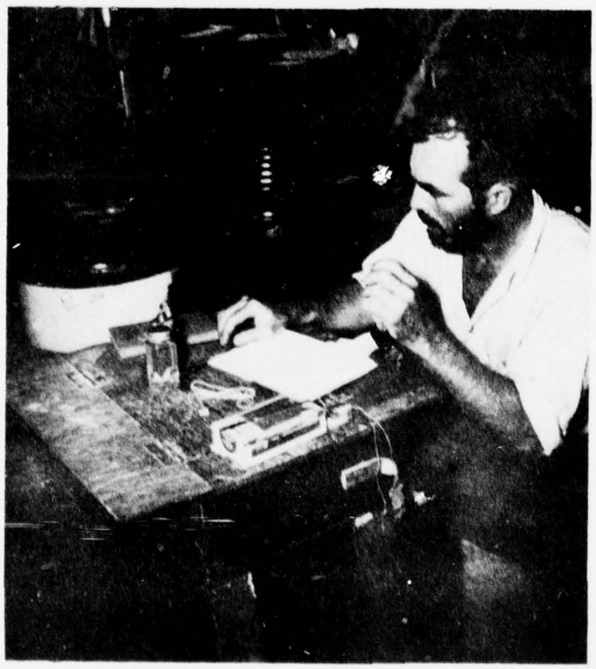

Figure 35. Dr. J.P.E. MORRISON records data on his folding desk and dissection table aboard LSM-382. ABCR Photo No. 5072-11.

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3.014 Land Animals at Bikini

Studies of land animals at Bikini, like the studies of marine invertebrates, were conducted along taxonomic and ecological lines, with special reference to changes in morphology and population observed in the target area. In this case again, a similar survey had been made in the spring and summer of 1946, thus making available data for purposes of comparison.

Both the 1946 and 1947 surveys were conducted by Dr. J.P.E. MORRISON, who gave particular attention to land snails, reptiles, birds and mammals. (Note: No amphibians are known to be represented in the Bikini area. A corollary study of insects was made by Dr. A. C. Cole, and is reported in Section 3.012.) Dr. Morrison employed ordinary collection methods in the field, supplemented by the use of small arms loaded with shot shells for the taking of reptiles, birds, and mammals. All specimens were prepared and/or placed in suitable containers and returned to laboratories in Chilton (APA-38). Specimens were taken on Bikini, Bokon, Enyu, Prayer, Reere, Biren, and Namu Islands of Bikini Atoll, and on five islands of Rongerik Atoll. Some birds were collected at sea, particularly southwest of Bikini Atoll.

Necessary laboratory facilities included materials for preserving and packaging, for shipment to the Smithsonian Institution in Washington, D.C. In addition, ordinary dissection and taxidermists' instruments were employed for purposes of making bird and mammal skins. Final taxonomic studies, and a comparison of 1947 data with that of the preceding year will be made at Smithsonian Institution by various members of the staff, including Dr. Morrison (mollusks). In addition to the general conclusions listed here, therefore, a more comprehensive report of the Smithsonian Institution will be published upon completion of the work, and this report will be available to the Chief of the Armed Forces Special Weapons Project.

Animals observed and/or collected at Bikini and Rongerik during the resurvey included land and fresh-water crustacea, land mollusks, reptiles, birds, and mammals. As a matter of convenience, sea birds and marine mammals also have been included in this report.

The several land-dwelling species of crabs, including the hermit crabs and their giant relative, the coconut crab, apparently were normal in all respects. As one example, a mature female coconut crab was observed spawning on the shore of Prayer Island. This same species, formerly hunted to the point of extinction by the natives, who used it as food, already was re-appearing in small numbers on Bikini Island in 1947, eighteen months after the natives were removed. Another species of true land crab, not previously seen in the area, was collected at Rongerik Atoll.

One of the most interesting discoveries of the 1947 resurvey was the finding of fresh-water ostracods (small crustacea) in coconut tree water holes of Bikini and Prayer Islands. How these little fresh-water forms have managed to reach a mid-Pacific atoll is not known. Ecologically, they may be displacing the mosquito larvae, which were not found in 1947, and perhaps no longer survive the DDT sprayings.

Collections of land snails were made on three islands of Bikini Atoll not previously visited by Dr. Morrison. Similar collections were effected on three additional islands of Rongerik Atoll, thus adding to the geographical records of the species concerned. Since the population exhibited no observal difference from its 1946 status, quantitative sampling on Bikini Island was not repeated because of the great amount of time required to concentrate, sort and count the

thousands of individual shells sometimes present in a single square yard of topsoil.

Re-examination and supplemental collections of small lizards on Bikini Atoll resulted in the discovery that there were four species present instead of three; two types of geckos being distinguished during the 1947 season. These lizards were collected both in the daytime and at night (to check on their nocturnal activity).

The bird population give evidence of being completely normal at and on Bikini Atoll in 1947, at least during the brief season (July and August) when birds were studied. The only land bird present, the New Zealand cuckoo (Urodynamis taitensis), is migratory, regularly spending its southern winters as far north as Bikini and Rongerik Atolls. The characteristic migratory shore birds, the golden plover, ruddy turnstone, and bristle-thighed curlew, were present on most of the islands in small numbers in 1947. The resident reef heron was as numerous and conspicuous as ever. The smaller sea birds, including the five resident species of terns (the crested, common noddy, white-capped noddy, black-naped, and fairy terns) were observed to be entirely normal in nesting habits for the season. Eggs or young of all these species were observed or taken during the (August) second nesting season of 1947. The sooty tern, regularly visited both Bikini and Rongerik Atolls during the 1947 period of observation. Apparently this species comes to these northern Marshall Atolls when it scatters over the Pacific after its breeding season. The larger sea birds -- the red-footed booby and the frigate bird -- resident on two of the southwesterly islands of Bikini Atoll, apparently were normal in 1947. In addition, the brown booby was seen in smaller numbers, near Bikini (and also Rongerik Atoll), but usually farther out at sea. It is not certain that this species breeds at or near Bikini; immature and adult plumaged specimens were taken at sea a few miles southwest of Bikini Atoll, and immature plumaged individuals were seen flying past the south side of Rongerik Atoll. The shearwaters, likewise birds of the open ocean, were seen near Bikini and Rongerik Atolls.

The only land mammal, the small native rat, (Rattus rattus exulans) was found normal in appearance, abundance, and activity, on Bikini, Namu, and Prayer Islands. Additional specimens for comparison were secured from Rongerik Atoll.

Two species of porpoise (or dolphin) were seen on several occasions about Bikini Atoll, and one of these species was seen about Rongerik. Unfortunately, it was not possible to secure specimens. On the 29th of July, 1947, a group of six small (sperm ?) whales were sighted at sea about four miles southwest of Boro Island on the southwest side of Bikini Atoll.

In brief, the land animals of Bikini Atoll apparently are morphologically enchanged, as observed and/or collected by Dr. Morrison during the Bikini Scientific Survey. This is true likewise of both the shore-birds and the sea-birds, whose food comes from the shallow (or deep) water areas of Bikini Atoll.

3.015 Plankton Studies at Bikini

Plankton is made up of innumerable small organisms, (both plants and animals) which float or are moved more or less passively by currents in fresh or salt water, and usually are small in size or microscopic. It constitutes the most important basic food of larger marine organisms, such as fishes. Plankton studies were not provided for in the early plans of the Bikini Scientific Resurvey, although some such studies were made in the Bikini area by Dr. Martin Johnson of Scripps Institution of Oceanography during the spring and early summer of 1946.

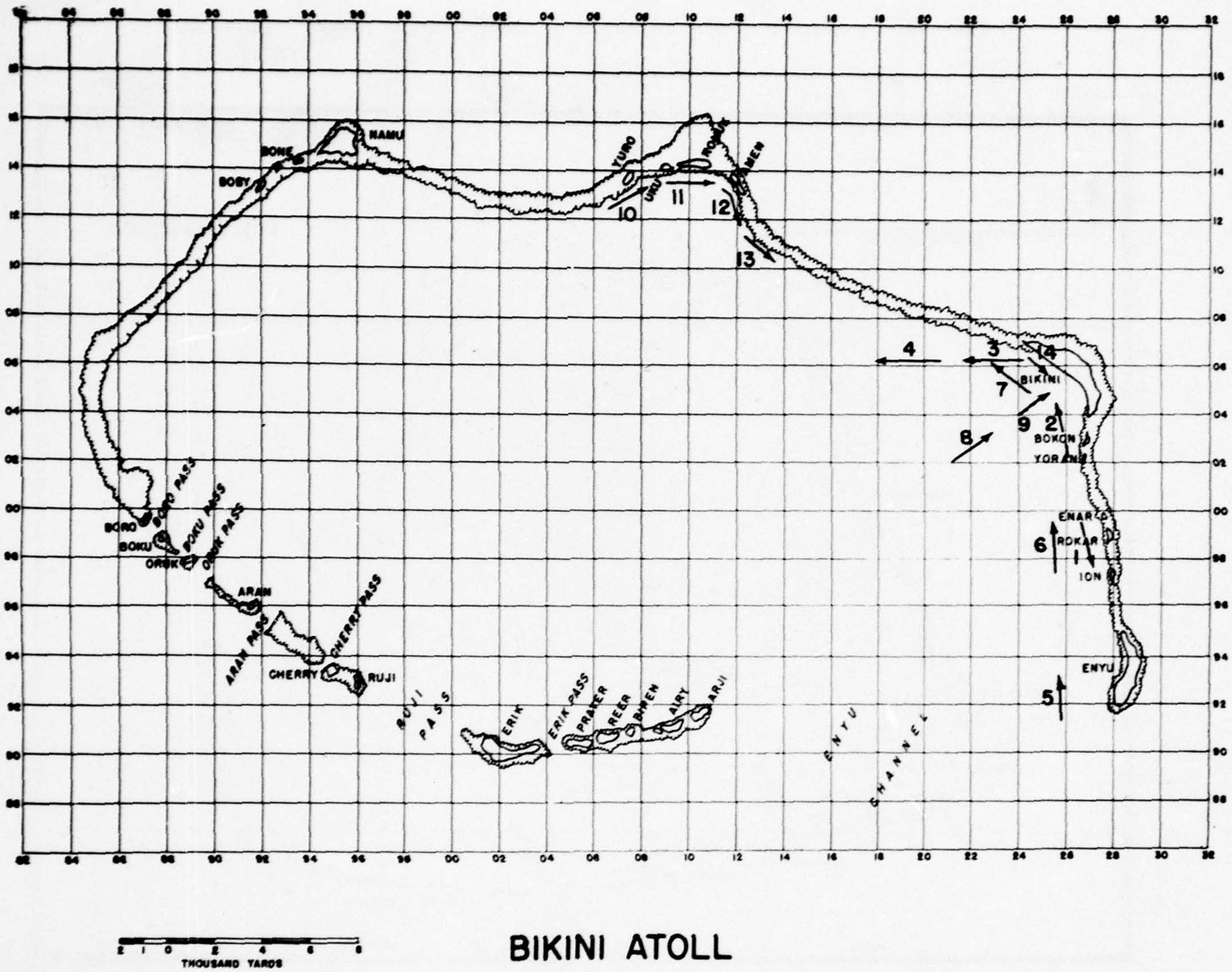

Figure 36. Plankton hauls made in Bikini Lagoon during the resurvey

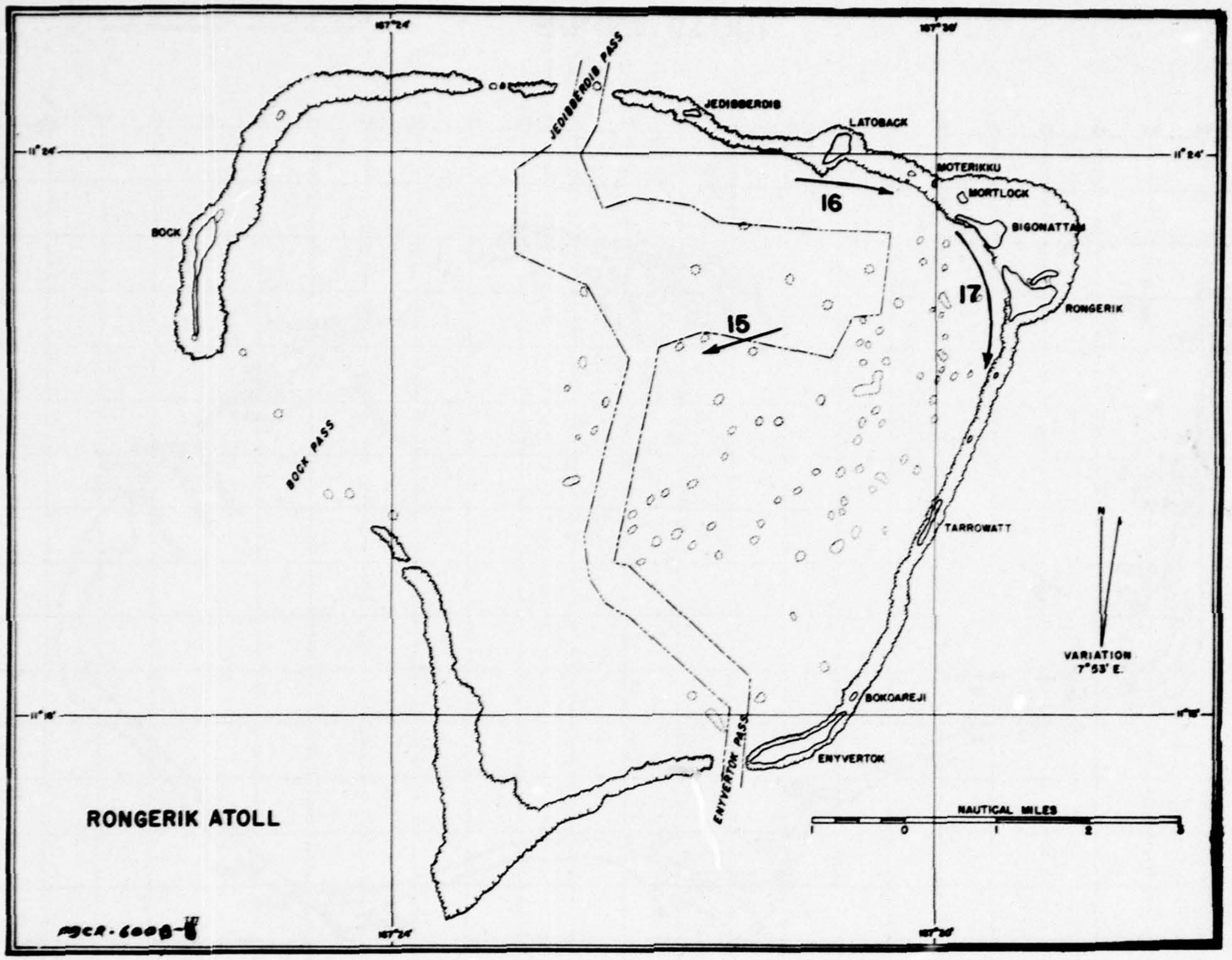

Figure 37. Plankton hauls made in Rongerik Lagoon during he resurvey.

During the brief stay of CDR Roger Revelle at Bikini subsequent to 15 July 1947, the question of plankton studies was discussed. At a conference held on 26 July 1947, and attended by CDR Revelle, CDR E. S. Gilfillan, Mr. V.C. Brock, Mr. J.C. Marr, Dr. L.P. Schultz and Dr. G.S. Myers, it was decided that apparent differences between the appearance of the water of Bikini Lagoon in 1946 and 1947 justified some attempt to obtain quantitative data on the plankton at Bikini for comparison with last years' results, and with the waters of radiologically uncontaminated Rongerik Atoll.

No special person was available for this work, but Dr. Myers, having some free time, volunteered to do some plankton towing with the only plankton net available, without, however, prejudicing the other work he had to do. It was understood that this work would be quantitative, that a boat would be assigned to Dr. Myers, and that CDR Revelle, immediately upon his return to the United States, would see that information regarding the plankton methods used last year by Dr. Johnson by sent airmail to Dr. Myers. (This information, however, did not reach Bikini until the plank on work there was concluded.)

In all, seventeen tow-net hauls for plankton were made in different parts of Bikini and Rongerik Lagoons during the period of 29 July 1947 to 14 August 1947 (see fig. 36 and fig. 37). The method used was a type of standard quantitative haul, involving the towing of a finemeshed net of a given type, for a given time, at a given depth, and at a given speed. All hauls were made at the surface (2-4 ft.depth) during daylight hours and were timed with a stop watch at 30 minutes each.

Unfortunately, the quantitative accuracy of the hauls was seriously impaired due to lack of certain necessary facilities. It was not possible, for example, to use the same boat continuously in towing operations, and no boats were available which could be slowed down to desired speeds of 1 to 1.5 kt. Comparison of any given plankton haul with that made by other investigators, either in the past or in the future, demands knowledge of the exact speed of towing and the time interval involved.

One of the few ways in which towing speed can be determined is through use of a patent log towed by the same boat that tows the net. Such gear, however, was not available at the time of the tests. The exact speed at which the net was towed is therefore not known, and there is no possibility of making quantitative comparisons with results obtained by Dr. Johnson in 1946. The best that could be done, using available facilities, was to estimate boat speed by behavior of the weighted net towed on a 50 ft. line, and make Dr. Myers' tows as comparable as possible.

Any more exact quantitative work, and the qualitative examination of the various plankton samples which were preserved in bottles of formalin solution will be carried out by Dr. Martin Johnson at Scripps Institution of Oceanography, to whom samples were sent.

Even considering the rule-of-thumb methods employed certain observations made in the course of the Bikini Scientific Resurvey were sufficiently striking to rank as reasonable conclusions. They are as follows:

a. The gross quantity of surface-water plankton in the target area (Bikini Lagoon) and in the middle of Rongerik Lagoon (at a comparable distance from the main island and the reefs of the atoll in each instance) appeared to be about the same during late July and August, 1947.

B. The gross amount of plankton in the shallow water of the lagoon, 1/4 mi. to 1/3 mi. off the beach of the main island, was much greater at Bikini than at Rongerik during late July and early August of 1947; the water was noticeably clearer at Rongerik.

C. Ctenophores (large, jelly-like planktonic animals, 2 in. to 4 in. long) were abundant at and near Chilton's anchorage during the entire period of the resurvey, but were rare or absent in other parts of the lagoon that were examined and at Rongerik as well (based both on hauls and on direct observation).

D. The gross quantity of plankton diminished as one went from a point near Bikini Island toward Amen Island or toward Enyu Channel during late July and August of 1947 with the following exception: surface water over and near the submerged atoll rim which forms Enyu Passage supported a very rich plankton fauna of copepods which are rare or absent in hauls made at other points. Enyu Passage is the observed habitat of large manta rays, which feed upon this copepod.

Further tentative conclusions based upon exchange of data resulting from the studies made by Mr. V.C. Brock, Mr. J.C. Marr, and Dr. L/P. Schultz were as follows:

A. Except for the unusual copepod plankton fauna in Enyu Channel over the submerged reef, the quantitatively richest plankton fauna in the eastern part of Bikini Lagoon during the summer of 1947 was between the target area and Bikini Island. There is nothing to indicate that this is a seasonal development. On the contrary, the poorer plankton taken at the same time and in a similar area at Rongerik indicates strongly that the Bikini situation is unique and due to something other than seasonal change.

B. Water between the target area and Bikini Island was much more turbid in 1947 than at the beginning of Operation Crossroads in 1946; clarity of the water in this area was observed to be decreasing during Operation Crossroads. A considerable part of the turbidity was due to presence of a rich plankton in 1947, and it may be inferred that this also was a contributory factor in 1946.

C. Quantitatively, the two atomic explosions do not appear to have affected plankton markedly in the target area, although further studies may reveal qualitative differences.

D. Presence of a rich copepod plankton in Enyu Passage and absence thereof near Bikini Island does not prove, but indicates strongly, that water coming into the lagoon through Enyu Passage had little to do with the comparatively rich plankton fauna found near Bikini Island in 1947.

E. There were no observations which indicated that the atomic explosions had anything to do with the inferred increase of plankton in a portion of Bikini Lagoon. In the combined opinion of the scientists concerned, it seemed much more likely that any actual increase was attributable to the deposition of nitrogenous waste products in the northeastern part of Bikini Lagoor by personnel of Operation Crossroads.

3.016 Counter-Room Activities

The counter-room established on Chilton (APA-38) was in actuality a service center, under the supervision of Dr. J.H. Roberson, and used by representatives of various other Scientific Groups, including Radiobiology and Radiochemistry, as indicated in Section 2.006. Samples of various materials, either before or after breakdown into component elements and compounds, were brought into the counter-room for determination of beta, gamma, and alpha activity.

Beta and gamma counting were done with argon-alcohol filled thin-window Geiger tubes and Tracerlab autoscalar circuits. An aluminum shelf arrangement, shielded with lead bricks, was found most satisfactory for holding samples. Backgrounds for the counters averaged about 21 counts per min. with the light shielding used. One beta counter each for the Radiochemistry and Radiobiology Groups generally was sufficient, though additional equipment was desired at times.

All alpha counting was done on University of Chicago type scale of eight parallel plate alpha counters. The two instruments supplied were adequate to meet the needs of the small Pu Chemistry Group. Backgrounds of these counters fluctuated from about 0.2 counts per min. to 1 count per min, possibly because of interference from ship's radio station. A special airconditioning installation kept the relative humidity of the counter room constant enough so that no humidity effect on the counters was observed. Two methane-flow proportional counters were installed, but were not used.

3.019 Low-Level Radiation Studies at Bikini

Low-level radiation studies of island soils were conducted at Bikini by Dr. J.H. Roberson and Mr. F.M. Simons. The purpose of these studies was to locate, and determine the nature and extent of radioactivity in the soils of various islands of the Bikini Atoll area.

A laboratory (see Section 2.006) was established on Bikini Island as a center for this work. This laboratory was equipped with an ion counter for measuring the radioactive content of atmosphere or soil; an ionization chamber for effecting separate alpha, gamma, and beta counts of soils; and Geiger counter apparatus (portable) for use in locating radioactive soils in the field.

Three types of measurements were made, as follows:

A. Geiger-counter measurements of gamma radiation distribution over the islands of Bikini Atoll.

B. Ion-counter measurements of the air over:

   1. The open sea
   2. Bikini Island
   3. The tar deposit northwest of Bikini Island

C. Ionization-chamber measurements of alpha, beta, and gamma-ray activity in samples of:

   1. Sand from the radiologically uncontaminated atoll of Rongerik
   2. Sand from the spit northwest of Bikini Island

NOTE: 3.017 and 3.018 will be published as a separate report.

3. Tar from the spit northwest of Bikini Island

<u>Gamma-ray distribution.</u> Measurements of the distribution of gamma-ray activity on the islands of the atoll were made with a portable radiation meter consisting of four Geiger tubes in parallel, connected to a VX-41 electrometer-tube integrating circuit. The instrument was placed so that the Geiger-tube assembly was 14cm above the surface of the ground in the area to be measured, and a stop watch was used to determine the time for a given amount of charge as delivered in pulses by the Geiger tubes to be recorded on the electrometer circuit. Plane surfaces were chosen for measurement whenever possible, to eliminate from the geometry of the counter the effects of proturberances. The sensitivity of the instrument was checked frequently with a Navy 23.88mg standard radium source, and the normal background of the uncontaminated atoll of Rongerik was measured to serve as a standard of comparison for readings taken at Bikini. Owing to the low loss design of the instrument, and the absence of any amplifying circuit, instrumental background arising from leakage or tube noise was insignificant and for purposes of these measurements could be ignored. The statistical error inherent in the measurements was less than 10% for the particular setting used, and it was constant throughout the range of readings taken.

The ratio of the normal background count on Rongerik to the count in excess of background, recorded 22m away from the standard radium source, was 15 to 100. At 22m from the 23.88mg of radium, the gamma-ray dosage rate should be approximately 10^{-3} r per day. While a Geiger counter is not reliable for comparing radiation-dosage rates unless the radiation sources being compared differ only in mass or in point source distance from the counter, a combination of the two statements above would seem to indicate a "normal background dosage" rate of 15×10^{-5} r per day. Because of the ambiguity of this figure, and the fact that portable instruments are more dependable for showing distribution than for giving absolute quantity values, the figures shown in Table XVII for the various locations measured are expressed only as ratios to normal background.

Faint traces of radioactivity were found on most of the lagoon beaches of the atoll, but with the exception of the areas noted below, the variations from the normal background were so small as to be of the same order as the statistical error of the instrument. Appreciable activity was found only on the lagoon side of Bikini Island, and on some of the larger sand bars between Bikini Island and Amen Island. While the measurements in any one place varied greatly from week to week (as the sand was continuously rearranged by lagoon wave-action) the activity in general was concentrated in a narrow strip between low and high tide levels, usually with a maximum at the high-tide level. The readings also increased towards the northwest tip of Bikini Island, but a short distance inward from the lagoon beach the readings fell off to background.

Only one area was found where the gamma-ray dosage rate was near tolerance. The high activity in the tar deposit on the spit northwest of Bikini Island was outside the range of the radiation meter, but a measurement with a Lauritsen electroscope indicated a maximum dosage rate of 0.4 r/24 hr, with the instrument placed directly over the center of activity. The non-uniform distribution of activity in the tar deposit suggested that the tar itself was not radioactive, but served only to hold small amounts of fission products in place. An analysis of the tar and sand mixture by the Radiochemistry Group indicated a gross beta activity of 0.8 microcuries per gm. The principle fission products present were cerium and praseodymium. Plutonium also was present in about the expected concentration.

Location	Ratio to background on Rongerik Island
Tar deposit on sand spit northwest of Bikini Island	Greater than 200
Sand on spit northwest of Bikini Island	1 to 10
Sani bars between Bikini and Amen Islands	1 to 10
Beaches (lagoon side) of Bikini Island (exclusive of debris)	1 to 5
Beaches (lagoon side) of Amen Islani (exclusive of debris)	1 to 2
Mainland of Bikini Island	1
Beaches on islands not listed above (exclusive of debris)	1 to 1.1

Table XVII. Summary of gamma-ray measurements on Bikini Atoll.

Air ionization measurements. Measurements of the ionization of the air were made with an ion counter consisting of an FP-54 plyotron-integrating electrometer circuit connected to a collecting system in an air tube, through which the air to be measured was drawn at a known rate. Timing the drift in the FP-54 plate current corresponding to a standard change in the potential of the collecting system, gave data from which can be calculated the number of ion-pairs formed in air per cm^{-3} per sec. It will be necessary, however, to return the instrument to Bartol Research Foundation for measurement of the capacity of the collecting system, before this calculation can be made, and analysis of the data completed.

Analysis of soil samples. Measurements on soil samples were made with the same instrument as decribed in the preceding paragraph, with the addition of an ionization chamber whose collecting system was connected to that of the ion counter. By using different filters, data was obtained on the relative amounts of alpha, beta, and gamma activity present in the sample. Owing to the conditions noted heretofore, it was necessary to postpone complete analysis of the measurements taken until after the return of the samples and the instruments to Bartol Research Foundation.

Except for the tar sample, activity was of such low order that it is doubtful whether any information not already submitted by other groups will be forthcoming from these field measurements. Communication between the Bartol Research Foundation and the Office of Naval Research can establish the extent of any further analysis of a more precise nature.

3.020 Army Engineering Studies at Bikini

A series of observations concerned with problems of the Corps of Engineers, U.S. Army, and especially the Civil Works Division thereof were made during the process of the Bikini Scientific Resurvey. These observations were carried out by Lieutenant Colonel E.C. Paules and Mr. J.F. Tarpley.

Problems of particular concern included the general effect of atomic bomb explosion upon harbors, the intensity of radiation at different intervals subsequent to such explosions, and the special types of engineering equipment required for repair or installation in a radiologically contaminated area, and for decontamination work within such a locality. Corollary problems related to the possibility of confining the spreading of dangerously radioactive waters, and the potential effects of atomic-bomb explosions upon watersheds.

Data bearing upon these problems was obtained first of all from the findings of various Scientific Groups working throughout the target area. Added facts were derived from examination of some gear similar to that used by the Army on the beaches of the various islands. Additional facts and inferences came from first-hand observation of conditions in and about the target area.

It is understood that a full report will be submitted through Project Officer, with the request that it be forwarded via appropriate channels, and with proper security clearance, to the Chief of Engineers. Much of the discussion contained therein is already incorporated in other sections of this Report. However, certain statements and recommendations pertaining especially to harbor installations are reviewed in the following paragraphs.

Atomic bomb effects upon harbor installations. Two types of atomic bomb explosions must be considered; explosion in the air and underwater explosion. Each may cause severe damage due to blast and/or radioactivity, but differences in effects will exist.

An atomic bomb exploded in the air over a harbor area will cause considerable damage over a wide area due to blast effect, liberation of heat, and initial radioactivity. Results are likely to include severe personnel casualties, and widespread physical damage due to shock and fires. However, residual radioactivity from fissions products is likely to be minimized, because they are carried upward by the hot column of the explosion, and may be widely dispersed by the wind. Blast and fire damage is likely to be heavy in the case of frame buildings; heavy masonary and reinforced concrete will probably fare somewhat better. Secondary damage and casualties may result from explosions of inflammable materials, fires, and delayed effects of exposure to radioactivity.

An atomic bomb exploded underwater in a harbor may be expected to sink ships in the vicinity, and do considerable damage to structures at or below the waterline due to the shock wave produced. The latter may include piers, breakwaters, and lock structures of basins or canals. Less blast or fire damage to structures ashore is likely to occur than in the case of an air explosion. On the other hand, contamination of waters and adjacent land areas with radioactive substances is likely to present a problem of considerable proportions. In an underwater explosion, radioactive materials rise with the column of mud and water thrown into the air by the blast; they then "drop out" with the mud and water over a rather limited area, the extent of dispersal depending somewhat upon the presence or absence of winds.

Radioactive materials in harbor waters. Certain fission products dropping into harbor waters will be in solution, but the majority will be in suspension. A certain proportion thereof may be expected to settle with sand and mud to the bottom, whereas others, remaining in suspension or solution, can be spread by tidal movements or other currents of water. This spreading of fission products decreases their concentration and the danger of radiation effects. Where there is little movement of water, it is probable that fission products will eventually settle to the bottom. In this location they present little hazard, since about 6 in. of water will absorb all of the beta and about 50% of the gamma radiation, and 5 ft. of water will reduce the relative intensity of the gamma radiation to about 0.001. On the other hand, radioactive substances in solution and suspension will continue to be hazardous until by continued dilution and decay their concentration is so reduced as to be of no consequence. The presence of such fission products creates a special problem for steam electric plants and similar establishments, which use harbor waters for cooling purposes.

When fission products are in a harbor area it will be necessary to prohibit the use of sea foods from these and adjoining waters, to prohibit swimming or bathing, and to observe all other general radiological safety precautions.

Radiological contamination of land areas. Concentration of fission products on land areas is likely to be variable, and to some extent dependent upon physical configuration of the surface, wind direction and velocity, and distance from the blast. Dangerously contaminated areas can be located by monitors, and plotted on maps. The intensity of radiation probably will decrease rapidly within the first few hours or days.

The most damaging effects upon a harbor and contiguous land areas undoubtedly would be produced if underwater and air explosions (atomic bombs) were to occur simultaneously, or nearly so. Such a circumstance would complicate greatly any rescue, damage control, or rehabilitation operations.

Detection and measurement of radioactivity. Instruments and procedures used by Radiological Safety Officers during the Bikini Scientific Resurvey appear to

be adequate for use in a damaged harbor area. The Model 263 Survey Meter is somewhat awkward to handle, however, and it has been recommended that a more satisfactory instrument be developed. In addition, the Model 263 Meter will locate but not measure high-intensity radiation; it has therefore been recommended that monitors also be equipped with a sturdy electroscope when entering areas where such intensities are likely to be encountered.

Radiological health and safety standards. Radiological health and safety standards and precautions as used in Operation Crossroads and during the Bikini Scientific Resurvey should be strictly observed. Continuing scientific studies of these matters are in progress, and standards and procedures will no doubt be modified as more knowledge is gained concerning the effects of radiation on human life. The present standard of allowable exposure rate of 0.1 r/24 hours is based on continued exposure day after day. No information was available on how much radiation the average man can withstand for limited emergency periods. Some tentative upper limit established in the light of present knowledge would be useful in terms of rescue and damage-control work which might be undertaken with a fair degree of safety in the early emergency periods following an atomic bomb explosion in a vital harbor area.

Special engineer equipment. It is believed that no special engineer equipment would be required in a radiologically contaminated area, since conventional equipment will function satisfactorily. Use of the equipment necessarily would be subject to limitations concerned with the radiological safety of operator and working crews. Frequent monitoring to detect any accumulations of radioactive materials, followed by decontamination where required, would be necessary. Equipment operators, being at some distance from the ground, and shielded partially from radiation by the equipment, probably could safely work longer hours than could men on the ground. Provision of suitable working clothes, heavy shoes, gloves, and respirators for use in dusty areas, combined with supervision by qualified radiological monitors, should permit efficient use of all types of engineer equipment.

Decontamination of radioactive areas. Requirements for decontamination of land areas will vary, depending upon the type of use to be made of the area, the kind and amount of radioactive materials present, and other considerations. While it is understood that certain procedures have been tested, or used by the Manhattan District, it is not understood that much investigation concerned with decontamination of large areas has been carried out. Removal of radioactive materials may be possible in some cases, or shielding may be practicable in others. Resurfacing of a highway or dock area may eliminate danger from strong beta-emitters, and other possibilities exist. It is believed that certain radioactive fission products may soon be available for experimental purposes.

Preventing spread of radioactive waters. Radioactivity of water is solely that of the materials in suspension or in solution in the water. Any spread of this water results in a dilution, and therefore a reduction in radioactive concentration. In the case of harbors, the reduction in concentration from natural exchange of harbor and sea water probably will be the most satisfactory means of reducing the concentration to safe levels. In certain harbor areas the exchange of water may be slight; more of the radioactive materials will sink to the bottom in such cases. The elimination of contamination from inland waterways, especially from streams tributary to city water supplies, is another problem which will require much study. A possibility is believed to exist in that filter beds and settling basins may prove satisfactory as means of removing radioactive particles from the water. Rapid decay of the majority of the radioactive fission products will result in early substantial reductions in radioactive concentrations.

Organization and procedures for rehabilitation. Damage control, repair, rehabilitation, and rescue work in a radiologically contaminated harbor area will be much more difficult and complex than that associated with an ordinary major air raid. The organization to handle this work must include direction by personnel who fully understand the radiological hazards, and must include trained personnel equipped to properly handle the radiological health and safety aspects. Complete control of all personnel entering the danger area, and decontamination of all personnel and materials leaving, must be assured until the area is declared to be radiologically safe. Severe fire loss and personnel casualties may occur in the first few hours, but many other lives may be needlessly lost by rushing into an area too soon.

Potential effects on watersheds. No information on the potential effects of an atomic bomb on watershed areas of a major city was obtained. It seems likely that an air explosion would have little or no effect, and that an underwater explosion in a large lake or reservoir would produce radioactive materials in the water which either would be deposited on the bottom or remain in suspension or in solution. Considerable study would be necessary to determine the most effective means of removing such materials from the water; filtering and settling are suggested as possibilities. Dilution and decay ultimately will assist in reducing initial dangers. Distillation of drinking water is possible, and might be necessary until sufficient reduction in concentration of radioactivity by other means is achieved.

Suggestions for future studies. It is believed that certain studies on radiological problems believed to be of particular concern to the Corps of Engineers should be undertaken or continued, to include the following items:

A. Studies similar to those made at Bikini, of all major United States harbors, to determine the interchange of water, the natural dilution rate from tidal action and currents, and the anticipated effects of such forces upon the spreading of fission products or lowering of their concentration.

B. Studies of sedimentation rates of various disturbed bottom materials in harbors, and their relationship to the anticipated settling of fission products.

C. Development of suitable methods for reducing or eliminating radiation hazards associated with land installations and equipment through the medium of tests with available fission products.

D. Development of training programs for Corps of Engineers personnel, to insure experience with, and understanding of radiological problems.

E. Development of methods for removing fission products from water. Studies should include the possibilities of employing filtration, settling basins, and precipitation.

F. Development and provision of suitable protective clothing for workers in radiologically contaminated areas.

G. Development of a planned organization to insure close cooperation of the Corps of Engineers with other military and civilian agencies in matters pertaining to rescue operations, damage control, and reconstruction.

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3.021 Aerological Data at Bikini

Aerological data was recorded during the resurvey by 1st Lt L.N. Chittock. The general purpose was to make such data available to Air Weather Service so that it could be used as a basis for determining the probable reliability of weather forecasts in the Bikini area.

For purposes of making weather observations, a station was set up on Bikini Island in connection with the Geological Laboratory. This station was operated by 1st Lt Chittock and an aerographer from Chilton (APA-38), and was equipped with pilot balloons, a thermograph, a theodolite, a barometer, and barograph.

Complete weather observations were made every six hours and a pilot balloon run every twelve hours. Information obtained was transmitted immediately to Pearl Harbor and Kwajalein to serve as an added basis in making weather forecasts. A day-to-day log of all weather phenomena also was kept, and this, together with all data taken, was incorporated in a report for Air Weather Service.

It was understood that final conclusions regarding the reliability of weather forecasts made for the Bikini area would be drawn by Air Weather Service after study of the data and weather log. In the event that such conclusions are published at a later date, it is presumed that they will be made available to the Chief of the Armed Forces Special Weapons Project.

The weather data and the weather log are incorporated in this report as Appendix A. No attempt was made to draw conclusions, because such conclusions could only be arrived at by Air Weather Service after considering the Bikini figures in the light of other data from the Pacific area and broad experience with weather forecasting.

3.022 Bacteriological Investigations at Bikini

In connection with Operation Crossroads in 1946, bacteriological studies were made of marine and soil environments subjected to the influence of bombs used in Tests A and B. It was considered desirable to extend certain phases of these original investigations within the program of the Bikini Scientific Resurvey. Lt E.L. Schmidt, USNR, was assigned to this investigation.

The time available for bacteriological studies was from 26 August 1947 to 3 September 1947, including a period of but four days for sampling. The objectives of the mission were threefold: (a) to examine numerically the distribution of bacteria in surface and bottom waters of Bikini Lagoon; (b) to examine numerically the distribution of bacteria in a core of bottom sediment from the target area; and (c) to conduct a study of biological oxygen demand in a sample of water from the target area. He was assisted by Mr. T. F. Goreau in making oxygen-content determinations of certain samples.

Original (1946) investigations were made in the Bikini area by Mr. D. B. Johnstone, whose report was available for purposes of comparison. Samples of the lagoon water were taken in Nansen bottles. Top samples came from within 3 ft. of the surface, and bottom samples from 6 ft. to 12 ft. above the bottom. The locations of all sampling sites were determined by fix positions, which are indicated in Table XVIII. A control sample of open sea water was obtained about 7 mi. southeast of Bikini Lagoon.

Samples were transferred to sterile, screw-cap bottles immediately upon surfacing, and these containers were placed under refrigeration until laboratory

tests could be instituted. At no time did the interval of time between collection of a sample and the initiation of laboratory work exceed 10 hr.

A core of bottom sediment was studied in the course of routine coring operations in the target area. Samples along the length of the core were taken with a flamed spatula, and placed in sterile containers. Relative measurements of gross beta activity were made along the length of the core at the same time. Bacteriological samples were placed under refrigeration until they were returned to the laboratory.

Final report upon oxygen-demand studies will be made to the Office of Naval Research upon their completion. Methods used in obtaining samples for these studies were essentially as described for the collection of other water samples, except that sterile, ground-glass stoppered bottles were used to receive the Nansen bottle contents.

Counts of the number of viable organisms present were made by the standard dilution-plate method, with results expressed as the number of bacteria per milliliter of sea water, or per gram of wet sediment. The medium used for culturing the samples was the same as that employed at the time of Operation Crossroads; namely, 1 gm peptone, 1 gm dextrose, 0.05 gm K_2HPO_4, 15 gm agar, and 1,000 ml sea water. The medium was poured into Petri dishes and mixed with the inoculum at a temperature of 42° C. Plates were incubated at room temperature (26° C to 28° C) for five days prior to counting. The foregoing procedure was followed in dealing with both water and sediment samples. The results of bacterial counts made on sea water samples are summarized in Table XVIII.

According to the studies reporting the distribution of bacteria in Bikini Lagoon waters just prior to the atomic bomb tests, surface waters averaged a few hundred bacteria per ml, whereas bottom water samples averaged 10 to 30 bateria per ml. Ten days after Test B it was noted that this distribution was reversed in the vicinity of the target area, with several thousands of bacteria per ml found in bottom water and less than 50 per ml in surface water. This comparatively high bottom water count was thought to be associated with agitation of bottom sediments which accompanied the bombs' detonation. The counts listed in Table XVIII are not considered to vary significantly from those recorded prior to the atomic bomb tests. Such deviations as appear, when compared with the average results of the original investigation cited above, are within the dispersion of the original data, and must be considered insignificant in the light of counting-method limitations and probable seasonal variations. No evidence of enhanced microbial development in bottom water, as observed shortly after Test B, was apparent in these investigations.

During the final day of coring operations in the target area, a single core of bottom sediment was taken and was examined from a bacteriological standpoint. Results of bacterial counts are given in Table XIX. The core was typical of the target-area sediment; it was about 100 in. in length, and consisted of white sand of nearly uniform particle size with a slight gradation to coarser fractions near the bottom. Sparsely dispersed throughout the core were carbon particles and oil streaks. Most striking from a bacteriological standpoint was the extreme paucity of visible organic matter, indicating a probable low bacterial population.

Location		Surface Water	Bottom Water
11° -35'-05"N; 165°-31'05" E	Target Area	25	300
11° -35'-01"N; 165°-30'-30"E;	Target Area	1,500	280
11° -35'-15"N; 165°-31'-10"E	Target Area	50	10
11° -34'140"N; 165°-27'-20"E	Bikini Lagoon	35	70
11° -30'-50"N; 165°-20'-20"E	Bikini Lagoon	130	10
11° -34'-00"N; 165°-38'-00"E	Control	10	---

Table XVIII. Results of bacterial counts taken on samples of sea water from Bikini Lagoon.

Depth of Sample From Top of Core	Gross Fission Product Activity (c/min/gm)	Number Viable Bacteria per gm wet sediment
6 in	1,525	80
36 in	2,220	30
64 in	1,220	10
96 in	178	10

Table XIX. Bacterial counts on a bottom-sediment core from the target area: 10°-35'-02"N; 165°-30'-21"E.

Bacterial counts cited in Table XIX must be interpreted in light of the fact that only a single core was examined. A limited amount of work a year ago on the surface layers of bottom sediments indicated that the normal population of natural sediments in the area was of the order of 100 to 200 bacteria per gm of wet sediment. It is highly probable that these data do not vary significantly from that cited, but on the basis of a single core such a possibility is not ruled out. The vertical distribution of bacteria noted is normal for bottom sediments, and attention is again called, as in the original studies, to the very low numbers of bacteria found here as compared with most ocean sediments. It would appear to be worthwhile to investigate further the distribution of bacteria in target area cores, as opposed to comparable sediments nearby, should the opportunity be provided.

3.023 Radiological Safety at Bikini

The mission of the Radiological Safety Section was to determine the magnitude of the radiological hazards existing within the area of the Bikini Scientific Resurvey, and to provide the Radiological Health Officer with the data and reports required to permit an accurate evaluation of the radiological situation and the formulation of policies and procedures necessary for the protection of personnel engaged in the operation. Lt Col C.E. Grant served as Radiological Safety Officer, and was assisted in this duty by the staff listed in Section 1.007 of Volume I.

In the accomplishment of this mission, Radiological Safety Officers accompanied all scientific work parties during the initial landings on the various islands and reef areas of Bikini Atoll, and continued to accompany these groups during the period 15 July 1947 through 28 August 1947, until such time as it had been determined that the specific area to be visited was free from hazardous concentrations of radioactive materials.

The Model 263 Survey Meter, manufactured by Victoreen Instrument Company, was used in all field and personnel monitoring operations. This instrument is capable of detecting both gamma, and beta plus gamma radiation, through the approximate range of 0.001 r/24 hours to 0.6 r/24 hours. Victoreen's Model 356 Alpha Meters also were included in the equipment of the Radiological Safety Section, but proved to be of no value in general terrain monitoring and of only limited value in the monitoring of underwater samples due to their comparatively low sensitivity.

Two types of underwater survey meters or probes were tested during the course of the deep-water diving operations conducted from the Coucal (ASR-8). The type of probe originally included in the resurvey equipment had a maximum range (gamma radiation only) of 0.035 r/24 hours, and consisted of a brass-cased Geiger tube, approximately 120 ft of shielded extension cable, and a Victoreen Model X-325 Counting Rate Meter. This instrument was tested prior to the initial dive made on the Saratoga and was found to be unsatisfactory since the length of the extension cable supplied was inadequate to permit a survey of the bottom in the vicinity of Saratoga's position. This lack of sufficient extension cable precluded the use of the probe throughout the target area.

On 28 July 1947, an experimental underwater radiological survey meter probe was received aboard Chilton (APA-38) from the Naval Research Laboratory. It consisted of a brass cylinder or probe containing seven Geiger tubes, the necessary electrical circuits and recording meters, and 225 ft of shielded extension cable, and had a sensitivity range of from approximately 5×10^{-5} r/24 hn to 5×10^{-3} r/24 hr, gamma radiation only. Limited tests were carried out aboard Coucal (ASR-8)

during the latter part of August, for the purpose of comparing this instrument with the type of probe described in the preceding paragraph, and a letter report covering the results of these trials was transmitted to the Bureau of Ships.

The high sensitivity of both types of probes resulted in their being of little value from the standpoint of radiological safety, and their usefulness as general underwater survey meters was definitely limited by the alternating current supply requirement of both instruments.

During the period from 15 July 1947 through 28 August 1947, two members of the Radiological Safety Section were assigned to Coucal (ASR-8) on a full-time basis to carry out the monitoring operations required in connection with the underwater inspection program being conducted from that ship, and to supervise the enforcement of the radiological safety and health precautions prescribed in the Radiological Safety and Health Annex (Appendix D, Volume I) of the Operation Plan. In general, these duties included the monitoring of the person, diving dress, and associated gear of each diver immediately following his return aboard ship from a dive; the preliminary monitoring of all samples brought to the surface by the divers; and the periodic checking of the ship itself to insure that no unnecessary accumulation of radioactive materials occurred.

When it had been determined that the general level of radiation throughout Bikini Atoll was well within the tolerance limit of 0.1 r/24 hr, all members of the Radiological Safety Section, with the exception of the Radiological Safety Officer and the two officers assigned to Coucal (ASR-8), were assigned collateral duties by the Project Officer as Planning Officers for the major Scientific Groups represented on the resurvey staff. While these officers continued to be responsible primarily for monitoring and the protection of personnel from a radiological standpoint, they were able to provide valuable assistance to the several Scientific Groups in arranging for boats, working parties, rations, and the miscellaneous field equipment required by the groups with which they worked. One officer served as both Radiological Safety Officer and Planning Officer for LCI(L)-615 throughout the period of bottom sampling and coring operations; a second officer acted in the same capacity during the shallow-diving operations carried on from an LCM; and the remaining three members of the section worked with the Fisheries, Biology, and Zoology Groups of the Scientific Staff.

A ban upon swimming in Bikini Lagoon and upon the eating of edible fruits or marine life taken anywhere in the area was established prior to the arrival of the expedition at Bikini, and was relaxed insofar as swimming at certain designated beaches and eating of edible fruits obtained on Bikini Island were concerned only after chemical analyses of lagoon water and fruits had indicated that no physiological hazard existed. The restriction against eating of any marine life whatsoever continued in effect throughout the period of the operations in Bikini Lagoon.

Although no great amount of difficulty was encountered in the use of the Victoreen Model 263 Survey Meters, it was found that these instruments presented a continuous maintenance and repair problem for the Electronics Repair Ship. They also proved to be too heavy and cumbersome to be transported over considerable distances by hand, and it was found necessary to improvise carrying straps for them by utilizing the web shoulder straps supplied with portable radios. It also became apparent from experience that rubber boat landing made through the surf necessitated the use of some sort of water-proof covering for the meter, if it was to function following the landing, and this requirement was met by improvising canvas cases for the meters from sea bags. Based upon the experience gained during the Bikini Scientific Resurvey, it is recommended that all Model 263 Survey Meters used under similar climatic and terrain conditions be equipped with a

carrying case designed for shoulder suspension, and fabricated or covered with some form of water-repellent material. It is believed that such cases would contribute to the portability of the instruments in the field, and would serve to protect them against damage by water and moisture, whether it be from water shipped during a small-boat landing, or from rain encountered during the course of monitoring operations.

Monitoring data was obtained by Radiological Safety Officers accompanying scientific work parties and by radiological reconnaissance parties operating independently of the Scientific Groups during the period from 15 July 1947 through 28 August 1947 from all of the major islands, and from representative islands in each group, with the exception of the sector at the western end of Bikini Lagoon (Boro, Boku, and Oruk Islands). A complete reconnaissance of the latter islands was not undertaken due to their relative unimportance to the resurvey operations, and their distance from the anchorage of Chilton (APA-38).

The survey of Bikini Atoll by the Radiological Safety Section during the above-mentioned period indicated that although certain isolated areas and accumulations of water-borne debris found on the lagoon beaches continued to produce beta and gamma radiation in excess of the tolerance limit of 0.1 r/24 hr, as outlined in Paragraph 8 (f) of letter, Bureau of Medicine and Surgery, Navy Department, EN10/Radsafe P2-4, dated 31 January 1947, the general level of residual beta and gamma radiation present throughout the land, beach, and exposed reef areas of the atoll was well within this same tolerance limit. It was noted that the debris along the beaches which continued to produce radiation consisted almost without exception of wood gratings and decking, life jackets, manila lines and fenders, life rings and rafts, provision crates, etc., all of which were assumed to have been blown overboard during Tests A and B, or thrown into the lagoon from the target ships by reboarding and damage-control parties following Test B.

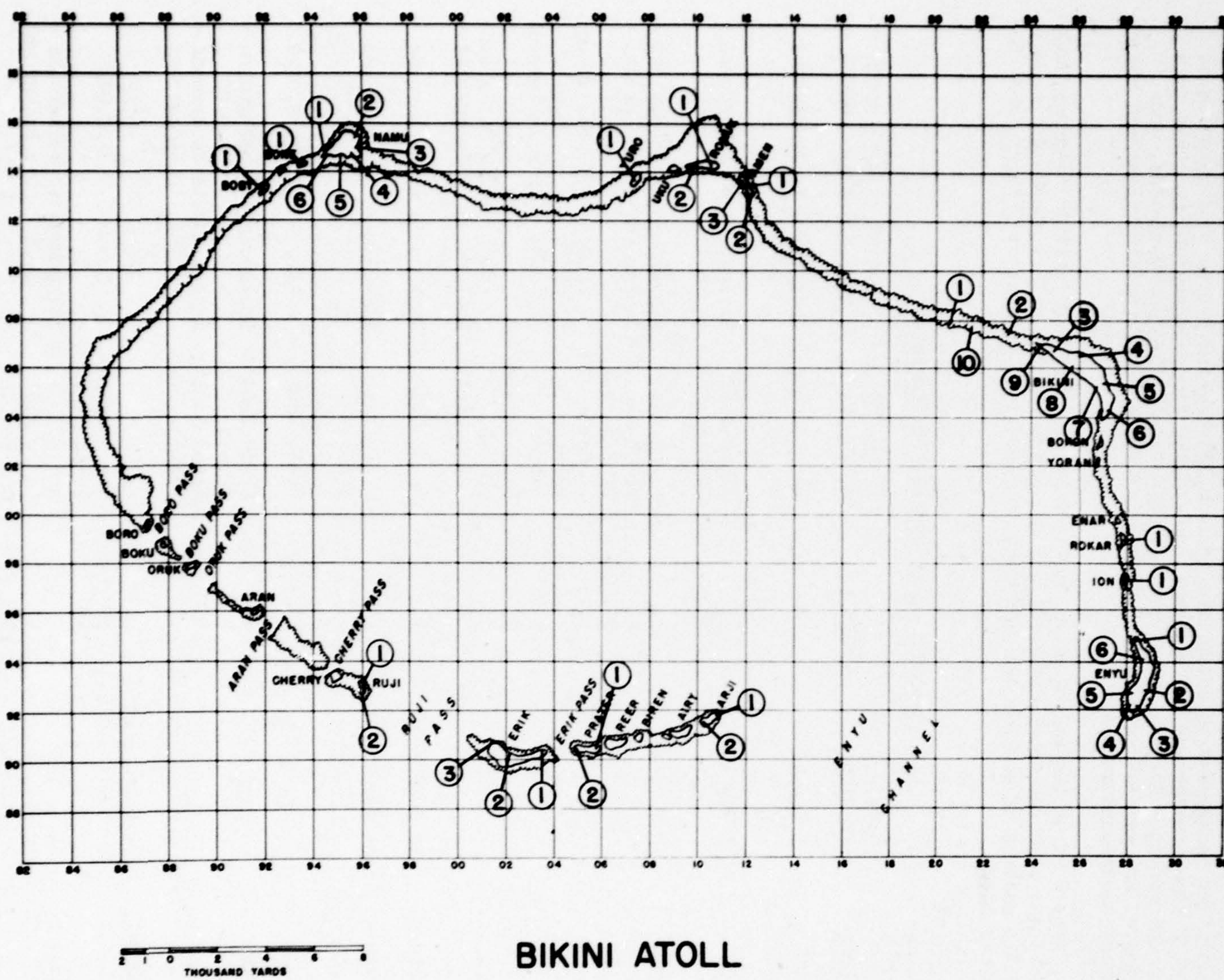
The maximum intensity observed by Radiological Safety Officers during the course of this resurvey was obtained on a deposit of tar or oil residue on a rock ledge located on the sand spit extending west of Bikini Island. This localized area produced a beta plus gamma reading of 0.6 r/24 hr, and a gamma reading of 0.18 r/24 hr.

A tabulation of representative survey-meter readings obtained during the course of the resurvey operation, together with an outline map of Bikini Atoll indicating the approximate locations at which the readings were taken, is attached hereto as figure 47. Additional data relative to radiation levels observed elsewhere in the lagoon are included in the detailed reports of the several Scientific Groups represented.

Prior to sailing from Bikini Lagoon, all ships comprising Task Group 10.12 were instructed to dispose of all lines, fenders, anchors, and miscellaneous deck gear exhibiting radiation in excess of the final clearance limits prescribed in BuShips-BuMed confidential letter, All/Crossroads/C-S(99)-(0), dated 22 November 1946, as amended by BuShips-BuMed confidential letter, S(99)-(0)(180-A), dated 17 December 1946. In the absence of a specific directive covering the final clearance limits established for diving dress and associated gear, Coucal (ASR-8) was instructed to retain all such equipment pending her return to Pearl Harbor, since monitoring had indicated that the contamination present was of a low order and presented no significant radiation hazard.

The monitoring of Chilton's (APA-38) hull at the waterline just prior to her departure from Bikini Lagoon on 29 August 1947 resulted in readings of only background and slightly above background, and the monitoring of her small boats and

[redacted]



BIKINI ATOLL

Figure 38. Representative beta and gamma readings obtained by the Radiological Safety Section at Bikini. Explanation of symbols will be found on the following page.

[redacted]

miscellaneous deck gear during the period from 29 August 1947 to 31 August 1947 failed to indicate the presence of any radiation in excess of these amounts. Samples of scale taken from Chilton's (APA-38) No. 2 evaporator on 1 September 1947 showed a beta plus gamma count of 1.7 times background and a gamma count of 1.25 times background in scale from the 2nd effect, and a beta plus gamma count of 2.3 times background and a gamma count of 1.3 times background in scale from the 1st effect. External monitoring of Chilton's (APA-38) evaporators, condensers, and salt-water systems indicated no evidence of radiation over and above normal background counts.

The work of the Radiological Safety Section, Bikini Scientific Resurvey, was concluded with the final monitoring of all shipboard laboratory spaces subsequent to the packing of samples and equipment, and prior to arrival of Chilton (APA-38) at San Diego.

Explanation of Symbols in Figure 47

ISLAND	DATE OF READING	LOCATION	SOURCE OF ACTIVITY	READING IN R/24 HOURS BETA + GAMMA	GAMMA
BOBY	5 Aug 47	1	(Beach Sand	Background to	Background +
			(Debris	0.2	0.03
BONE	5 Aug 47	1	(Beach Sand	Background to	Background +
			(Debris	0.15	0.03
NAMU	22 July 47	1	Beach Sand	Background to	Background +
		2	Beach Sand	Background to	Background +
		3	(Oil Residue (on Sand	0.01	2 x Background
			(Debris	0.20	0.03
		4	Debris	0.03	2 x Background
		5	Oil Residue on Sand	0.01	2 x Background
		6	Beach Sand	Background to	Background +
YURO	16 July 47	1	Beach Sand	Background to	Background +
ROMUK	22 Aug 47	1	(Beach Sand	Background to	Background +
			(Debris	0.30	0.05
		2	(Debris	0.12	0.01
			(Beach Sand	Background to	Background
AMEN	16 July 47	1	Beach Sand	Background to	Background +
		2	Debris	0.05	0.005
		3	(Beach Sand	Background to	Background +
			(Debris	0.001	Background
BIKINI	15-20 July 47	1	Beach Sand	0.002	0.001
		2	Beach Sand	0.002	0.001
		3-8	Beach Sand and Soil	Background to	Background +
		9	Beach Sand	0.03	2 x Background
		10	Oil Residue on Rock Ledge	0.60	0.18

ISLAND	DATE OF READING	LOCATION	SOURCE OF ACTIVITY	READING IN R/24 HOURS BETA + GAMMA	GAMMA
ROKAR	16 July 47	1	Beach Sand	Background to Background +	
ION	16 July 47	1	Beach Sand	Background to Background +	
ENYU	19 July 47	1-3	Beach Sand	Background to Background +	
		4	Debris	0.02	0.001
		5	Debris	0.30	0.025
		6	Beach Sand	Background to Background +	
ARJI	26 July 47	1	Beach Sand	Background to Background +	
		2	(Debris	0.03	2 x Background
			(Beach Sand	Background to Background +	
PRAYER	15-16 July 47	1	Beach Sand	Background to Background +	
		2	(Beach Sand	Background to Background +	
			(Debris	0.03	0.001
ERIK	13 Aug 47	1	Beach Sand	Background to Background +	
		2	Debris	0.1	0.012
		3	(Debris	0.2	0.04
			(Beach Sand	Background to Background +	
RUJI	13 Aug 47	1	Beach Sand	Background to Background +	
		2	(Debris	0.02	2 x Background
			(Beach Sand	Background to Background +	

3.024 Radiological Health at Bikini

The mission of the Radiological Health Section was to protect all personnel engaged in the Bikini Scientific Resurvey operation from any radiological health hazards which might be encountered. The Section was under the direction of Commander H.S. Etter, Medical Corps, who was assisted by three pharmacist's mates.

Medical examinations. Since it was imperative to eliminate at the outset any personnel who had chronic infections or chronic conditions of any nature; particularly respiratory or skin infections, blood dyscrasias, or any pre-cancerous lesions; all personnel, both military and civilian, who were to be actively engaged in the resurvey operation, were given a physical examination prior to acceptance. This examination included a complete blood count, an erythrocyte sedimentation rate, an X-Ray of the chest, complete urinalysis, fingerprints, and a general physical examination recorded on NavMed Form "Y". All personnel of Task Group 10.12 underwent the above-mentioned laboratory tests, but only military and civilian personnel actually engaged in the resurvey work received the general physical examination. The following criteria for disqualification from participation, based upon laboratory findings, were employed:

A. Red blood counts below 3.5 million and above 6.0 million

B. Hemoglobin below 11 grams (75%)

C. White blood counts below 4,000 and above 10,000

D. Sedimentation rate below 4,000 and above 10,000

E. Differential granulocyte counts below 3,000 and above 7,500 per mm^3

F. Differential lymphocyte counts below 1,200 and above 4,000 per mm^3

G. Presence of immature white cells, nucleated red cells, or hyper-segmented granulocytes (6 or more lobes) in the differential smears

H. Persistently abnormal urinalysis

Upon completion of resurvey operations the physical examination outlined above, with the exception of the chest X-Ray and fingerprints, was repeated in the case of all personnel who had been actively engaged in resurvey activities. No further examination was deemed necessary for personnel who did not participate actively.

Photographic dosimetry. By way of protecting individuals against continued overexposure to radiation, a photographic dosimetry unit was set up to issue, receive and process film badges. These badges, which totalize the amount of radiation received, initially were issued daily to personnel engaged in all scientific expeditions, including shallow-water diving operations; and to all deep-water divers. They were collected at the end of each day, after work parties had returned to the ship, and processed and interpreted in the photographic-dosimetry laboratory on the same evening. After the first week of operations, when it became apparent that daily exposure was insufficient to produce a significant effect, badges were processed weekly instead of daily. A week's integrated exposure proved insufficient to produce a computable result, so the required wearing of badges was discontinued, except in the case of deep-water diving operations, and whenever scientific expeditions went out to previously unvisited areas of Bikini Atoll.

In the case of the deep-water diving operations, three badges were worn within

the diving suit on each dive; one in the shoe top, one at hip level, and one at shoulder or chest level. These badges were developed daily for the first two weeks, and then after every three dives for the remainder of all diving operations. In addition, each diver carried a pencil-type pocket dosimeter within his suit.

Gear employed in the photographic dosimetry work was as follows:

A. An Ansco-Sweet densitometer for reading the densities of films exposed in the film badges

B. Type K film badges obtained from Radiation Laboratory, San Francisco Naval Shipyard (500 badges)

C. Holders and DuPont film packets obtained from Atomic Energy Commission at Oak Ridge, Tennessee (300 holders and 5,000 packets)

The Type K film, as supplied by Naval Radiation Laboratory, has a thin lead cross upon it, which stops the beta radiation but is penetrated by the gamma radiation; the area not covered by the cross is exposed to both beta and gamma radiation. The type of badge supplied by the Atomic Energy Commission also is designed for beta and gamma radiation. It consists of a film packet in a stainless steel holder, the upper half of the packet being shielded on both sides with cadmium. This upper section is used for gamma-ray dosimetry. A window in the lower half of the steel holder permits exposure of the packet to both beta and gamma radiation. During the latter part of the resurvey operation the steel holder was not used. Film packets with cadmium shields were inserted into rubber sheaths for protection against water.

Film badges of each type were exposed to a standard radium source for calibration. Each type of film badge had an approximate sensitivity range of from 0.02 r to 2.0 r.

During the period from 15 July to 29 August 1947, a total of 572 film badges were developed, and the exposures interpreted. None of these badges was found to have been exposed to sufficient radiation to acquire computable density. From film-badge data it was determined that there were no personnel exposures in excess of the daily tolerance limit of 0.1 r, beta plus gamma. All developed badges were alphabetically filed, and will be permanently stored at the Radiation Laboratory, San Francisco Naval Shipyard, as a permanent exposure record for personnel connected with this resurvey operation.

It should be emphasized that in operations such as the Bikini Scientific Resurvey it often is necessary to protect film badges with rubber sheaths because otherwise they become water-soaked. In the initial stages of the operation many badges were completely ruined by failure to observe this precaution, even when the majority of the work was done on dry land. Frequently the badges became soaked while wearers were returning to the ships in small boats.

General precautions. Until radiological clearance was given any particular area or island, personnel entering such an area wore full suits of protective clothing.

Before the start of operations in Bikini Lagoon, a decontamination station was set up in a forward troop head. This station was secured from adjacent living spaces. Contaminated personnel entered on the starboard side, removed clothing, scrubbed and showered, were monitored, dressed in clean clothing, and left the station on the port side. Scrub brushes, soap, towels, and a bin for contaminated clothing were provided. The contaminated and clean sides of the station were

clearly marked by appropriate signs. No contamination causing combined beta-gamma reading exceeding twice background was at any time left on the body of any personnel, and no clothing was worn which showed a combined beta-gamma reading exceeding twice background.

3.025 Summary

The principal result of the BIKINI SCIENTIFIC RESURVEY was to show that the atomic explosions caused only minor, transient disturbance to the plant and animal populations of the area, the effects of which have almost completely disappeared after one year's time. Some plants and animals in the immediate area of the underwater explosion were killed and some highly radioactive plants, fish and invertebrates of impaired vitality were found in the three weeks following test Baker. One year later, a most careful search of the islands, reefs, and lagoon by some twenty very well-qualified and well-equipped and well-supported biologists, over half of whom had made extensive studies of the same areas before the explosion, revealed no changes in population, numbers, or composition, and no physiological damage which definitely could be ascribed to the explosion. The nearest thing to a case of definite damage from the products of the explosions is furnished by some dying corals on the reef between Amen and Bikini Islands. These corals (Heliopora) were observed to be in fine condition a few weeks before test Baker. At the time of the explosion the tops of the coral clumps were about a foot under water, and the tide was rising. They may have been killed by radioactive fission products definitely known to have washed over the reef after raining down from the base surge. More probable causes of their death are contamination by oil from the sunken ships, patches of which can still be found on almost all the reefs and beaches, or by heavy rain during one of the lowest tides. Corals are easily killed by fresh water. The question of what happened to these particular corals remains open.

Large amounts of radioactive material still exist on the lagoon bottom. Above the water, the external radiation is appreciably greater than background only on the sand spit at the northern end of Bikini Island and the adjoining reef, and near debris from the target ships cast upon various beaches. Even there, it provides no physiological hazard. In the habitable portions of the islands, any radiation from fission products is so weak as to be completely lost in the normal background. In the waters of the lagoon, the residual radioactivity from the bomb is similarly lost in the radioactivity normally present in sea water the world over. Of approximately a thousand plant and animal samples, mostly fish, which were counted or analyzed, the average radioactivity per unit weight was approximately fifty per cent more than that of the body of a man who has had no exposure to radium, fissionable material, or fission products; and in only one sample, a sponge, was the energy per unit volume being received from radioactivity as much as it would have been from the accepted tolerance of external radiation, 0.1 R/24 hours. Other than fish, no food product was found which contained more than twice the normal radioactivity of human flesh. The maximum amount of plutonium found in any part of any fish was 3×10^{-10} grams per gram of wet tissue. When it is remembered that two of the dangerous long-life fission products, strontium and cesium, are not now present at Bikini and that the fission product activity still present there will have decayed to about 30 per cent of its present value after one more year, and that from food eaten, somewhere between 1 and 10 per cent of the radioactive material is retained by the body, it becomes obvious that after a few more years these islands will constitute relatively slight radioactive hazard to any one. Nevertheless, definite predictions cannot yet be made as to whether the radioactivity will soon become sufficiently diluted to permit permanent reoccupation of the atoll. The primary considerations in such relocation would be medico-legal.

As Chilton (APA-38) crossed the sill of Enyu Channel, it was immediately observed that the water, instead of being marvelously clear as it had been when the first units of Joint Task Force ONE entered the lagoon, was as opaque as that off Point Loma and it was at first supposed that this decrease in transparency might reflect a major change in the biological situation. An increase in opacity had occurred during the period from March to August 1946 when the lagoon was occupied by Joint Task Force ONE. It was assumed that this was due to the increased organic activity in the water resulting from the large amounts of organic nutrient materials put into the water by the Task Force. Since the amount of phosphorus and nitrogen contributed by the Task Force was only a small fraction of that normally present in the water, it is difficult to believe that this effect alone could persist for a year in view of the continual partial flushing of the water of the lagoon. Immediately after test Baker there was a large increase in the bacterial population, probably due to nutrients from organisms killed by the explosion. It appears possible that this increase in bacterial numbers presaged a change in the biological balance which resulted in a more or less permanent increase in organic activity and corresponding decrease in transparency of water. Studies of plankton population during the Resurvey, however, showed no obvious differences from 1946, and bacteriological observations later in the summer showed that bacterial levels had resumed their pre-explosion status. The observed decrease in transparency may be a normal, seasonal effect occurring in the summertime when long swells from the South Pacific enter the lagoon through Enyu Channel and stir up the bottom sediment. These materials are below the depth that can be affected by the short, high wind-waves of winter and spring. It is quite possible that the fine materials stirred up by the test Baker explosion and redeposited on the bottom surface are more easily kept in suspension by wave action than the bottom sediment existing prior to test Baker. Essential data that would be critical in resolving this problem would be measurements of the transparency in the eastern part of the lagoon during the winter months.

On the basis of the chemists' work some detail can now be added to the phenomena of the Baker explosion. Within a tenth of a second after the explosion, some 275-day cerium 144, which is one of the more abundant and troublesome long-lived isotopes, had been formed as the end-product of a fast radioactive chain beginning with xenon 144. Under the great heat and pressure still prevailing, this was mineralized, in a way not possible in a reasonable amount of time in the laboratory, to an extremely insoluble form. Within a few minutes a large fraction of all the fission products which ultimately remained in the area were in the water of the lagoon. An exception was 53-day strontium 89, another long-lived substance, some of which was still in the form of 3-minute xenon and was carried to the outer edge of the area of precipitation. The result was that only about half of the amount of strontium 89 finally produced was deposited in the target area. After the explosion, the water in the target area was turbid for more than an hour with bottom debris, some very finely powdered. Photographs taken shortly after the cloud cleared away show an unsymmetrical patch of milky water about the size of the target array. All the fissionable material from the explosion and the following long-lived fission products: yttrium, zirconium, columbium, antimony, praseodymium, element 61 and europium, as well as many short-lived fission products, were quickly and permanently adsorbed on the suspended material and carried to the bottom, where all but an insignificant fraction still are. Thirty-three-year cesium was not adsorbed because of the large quantity of the chemically similar element sodium already present. Twenty-five-year and shorter-lived radio-strontium were not adsorbed because the relatively large amount of chemically identical neutral strontium normally present in sea water had saturated the surface of the adsorbent. Only a small fraction of the various radioactive ruthenium isotopes was carried down because of the tendency

of this element to form complex anions with the chlorine in the sea water. After six months, more than 99 per cent of these soluble elements had been carried off to sea by the normal flushing processes occurring in the lagoon. Loss of strontium 91 by this process had the effect of diminishing the amount of its daughter, 53-day yttrium 91, which otherwise would have been a more significant contributor to the present activity of the bottom.

The radioactive materials carried down by the process just described are by no means evenly or symmetrically distributed on the bottom; the details of the distribution are so complex that only a rough, qualitative estimate of the total radioactive material on the bottom has been possible. The greater part of the material was deposited near the center of the target array, but patches of as much as forty-fold higher activity per unit weight are found further out, and the data suggested that the most active material was deposited near the outer edge of the column. Generally, the most active deposits are at the surface of the bottom, but in some places rich deposits are overlaid by poorer ones.

At the present time worms and sea cucumbers are burrowing actively in and eating the highly radioactive bottom mud. Most of this passes right through them, and some of the feces are left on top, where bacteria compost them, returning most of the active material to the mud. However, some is left available to plants, which grow on the altered material. These plants are eaten by small fish, which pass almost all the radioactive material through the gut. Small fish with the small fraction of radioactive material they have retained in their tissues are in turn eaten by large fish, which again eliminate most of the radioactivity, carrying some of it to distant parts of the lagoon and even outside. Plants remote from the explosion center get traces of radioactive material in this way, and the cycle is continued. The net tendency is to spread the material evenly over the lagoon bottom and to carry a certain amount of it out to sea.

It is time to consider the ultimate fate of the radioactive material now in or on the lagoon bottom. Fission product attrition by decay is much faster than by biological processes. Within a year, decay alone will have reduced the activity in total energy to 30 per cent of what it is now, and the flesh of the lagoon fish will not, on the average, be as radioactive as normal human flesh. In five years, only 4 per cent of the present activity will remain, and radioactivity of the fish will be completely lost in the background. In 10 years, less than 1 per cent of the present fission product activity will remain in Bikini lagoon. For plutonium, attrition by biological processes, although probably less than 1 per cent per year, no doubt will outstrip radioactive decay. The present activity from plutonium will remain substantially unchanged for many years, but the rate of transfer to foods will be so slow as to constitute little hazard.

The idea that plants and animals may concentrate radioactive material has often been expressed. By way of definition, a radioactive material may be termed concentrated when the amount of radioactive energy per second per unit weight of organic tissue exceeds the amount per unit weight of soil or water in the case of a plant, or the average for food received in the case of a fish or other animal. Concentrations of radioactivity by plants up to several hundred fold had definitely occurred in the first two weeks after test Baker. No fish collected at that time exhibited any gross concentration, though the gills, livers and spleens of some of the fish did show concentrations as high as a factor of 10 over the stomach contents. The plants collected in the lagoon a year later, after careful washing with salt water to remove the silt, were in general much less radioactive than the coral rock on which they grew. Exceptions to this statement occurred chiefly in the case of Halimeda which exhibited counting rates as high as

three or four times background. Only one fish collected (out of approximately a thousand analyzed) in 1947 showed a higher concentration of radioactivity in the entire organism than in the feces. However, the average concentration in the liver and spleen was about 50 per cent higher than in the feces, and the average radioactivity in the kidneys and gonads was also frequently considerably higher.

The marked concentration of radioactivity by plants two weeks after test Baker and the reverse effect a year later undoubtedly reflect the different identities of preponderant radiators at the two times. In 1946 the principal fission products were strontium, barium, bromine, rubidium, ruthenium, iodine and cesium. A year later, because of radioactive decay or because of the flushing of the sea water, nearly all the radioactivity from these substances had been eliminated in the lagoon, and only the heavier elements, yttrium, cerium, zirconium and columbium, remain. As shown by Overstreet and Jacobson these are not appreciably absorbed by plants.

One of the most discussed effects of radioactivity is the possibility of producing genetic changes. At Bikini more than 1000 species of organisms have been exposed to radioactivity, and many have reproduced through at least one generation. A careful search of the area by competent biologists, including ichthyologists, botanists, invertebrate zoologists, and entomologists, in the course of which tens of thousands of specimens were examined, failed to reveal definite evidence of aberrant forms. Since it is known that mutations produced by radiation almost invariably have negative survival value, this result was not unexpected. No interference with the reproductive functions of sea-urchins taken from the most heavily irradiated portion of the reef could be detected. The only observed effect considered related to the atomic bomb explosions was an increase in catalase activity in three genera of algae taken in an area which was probably exposed to high intensities of radiation.

In using the results of the Bikini Resurvey, with other information, in planning the defense of the United States, one point needs special consideration. At Bikini, three abundant long-lived fission products, strontium, cesium and ruthenium, were not carried down by the mud because sea water contains abundant material in solution to hold them back. In fresh water and on land this will not be the case, and these elements will contribute detectible radiation in heavily contaminated areas for many years. Another point worth noting is the sharpness with which the present contaminated area is now defined. During the first few weeks after the explosion there were many fission products remaining in the water, and the boundary of the contaminated area was diffuse and variable from day to day, and it was only after these had decayed or washed out of the area that the boundaries became sharp. In fresh water or on land all fission products may be expected to become fixed in the soil or mud almost at once, and the boundaries will be sharp from the beginning. One will either be in a heavily contaminated area, or definitely out of it.

In addition to determining the long-term effects of atomic bomb detonation which might be of military interest, it was the purpose of the Resurvey to conduct researches of a purely scientific nature. Many of these had been begun or were suggested during the Crossroads Operation. During the Resurvey, information was added to the fund of knowledge concerning the geology, oceanography and biology of Bikini Atoll. Some details of these studies are included in this report.

The foregoing summary sets forth the present opinion of AFSWP staff. Appraisal must await evaluation by the scientists and publication in Scientific journals.

APPENDIX

A: Aerological Data Collected at Bikini

APPENDIX A

AEROLOGICAL DATA AT BIKINI - 1947

WEATHER LOG

15 July

Arrived at Bikini at 1100L. Weather normal; scattered fair weather; CU bases 2,000 ft; tops 5,000 ft. What appeared to be "Intertropical" activity was in the distance over the southern horizon, oriented east-west with CBs built up to an estimated 15,000 or 18,000 ft, with 9/10 CS apparently blown off the tops of the CBs. The system approached slowly until by early afternoon virga and low scud clouds were visible within 12 to 15 mi. of the CHILTON. By 1800L the system had degenerated markedly and had receded southward.

16 July

Normal "trade" weather. 3/10 CU based 2,000 ft, tops 5,000 ft; no build-ups. About 2300L a heavy rain squall passed over CHILTON lasting about 30 min. The wind reached 42 kt and shifted from NE to SE; then settled back to ENE by end of squall.

17 July

Normal weather. 3/10 CU at 2,000 ft.

18 July

Rain showers early morning before daybreak. Normal weather throughout day; 4/10 CU at 2,000 ft.

19 July

Heavy rain showers during early hours before daybreak. 3/10 CU at 2,000 ft. remainder of day.

20 July

Moderate rain showers during early morning hours before daybreak. 3/10 CU at 2,000 ft. remainder of day.

21 July

Rain showers during the early hours before daybreak. Sky variable between 3/10 and 7/10 CU remainder of day. Trade winds increasing. Sea choppy. The nocturnal showers are coming very regularly, and usually between midnight and 0400L.

22 July

Rain showers during early morning hours. Probable easterly wave approaching rapidly from the east starting 1000L, with 9/10 CB; tops estimated 18,000 ft; oriented N-S. Heavy rain showers started by 1030L with winds ENE, 30 to 40 kt. 1200L: Line of heavy CB south, oriented east and west, thunder heard for 1/2 hour. Bases CB 1,500 ft, tops 18,000 ft. CBs with showers continued to pass overhead remainder of afternoon.

23 July

Heavy rain most of night. Wind shifted during the night from ENE to ESE. Situation assumed to be the intersection of an easterly wave and an intertropical front. Sky became entirely clear by day break with exceptional visibility as in extremely unstable air, however, no instability showers occurred all day nor was there any CU activity of any kind.

24 July

Usual nocturnal showers during early hours before sunrise. No showers during the day. Sky variable between scattered and broken CU at 2,000 ft.

25 July

Usual nocturnal showers. Scattered CS with scattered fair-weather CU entire day. Normal trade winds.

26 July

Usual nocturnal showers. There was more than the normal amount (8/10 coverage) of CBs with distant rain squalls the entire day. The CBs had no special orientation except that during midmorning the CU and CBs to the east were on a line extending north and south with the cloud tops at the northern end of the line at 5,000 ft. building up gradually until the tops at the southern end were well above 20,000 ft. The CBs at the southern third of the line had heavy rain beneath them. Surface winds varied back and forth between ENE and ESE; five to ten kt.

27 July

Usual nocturnal showers. Scattered CS (high) with broken, low CU at 2,000 ft. and with occasional build-ups to 15,000 ft; entire day. Occasional light rain showers from noon until 2100L.

28 July

The day started out with normal scattered CU at 2,000 ft. with no build-ups.
1400L: Clouds beginning to build up to the south in a line oriented east to west with tops going into CS typical of intertropical activity.
1500L: Line of build-ups mentioned above now within 15 mi. of CHILTON (point of observation). Bases of clouds very dark, virga visible along most of southern horizon. Bases estimated 1,500 ft. with numerous patches of rapidly moving scud at 800 ft. Tops of CBs estimated at 18,000 to 20,000 ft.
1630L: Ceiling lowered rapidly to 500 ft; wind easterly 35 kt; heavy rain falling at present.
1730L: Rain stopped. Ceiling still low; winds subsided, heavy showers in all directions but not overhead. No changes remainder of evening.

29 July

Day dawned clear with very good visibility such as in unstable air. Heavy swells penetrating into Bikini Lagoon from the south. Wind shifted during the night to the SSE; 12 kt. Wind persisted from a southeasterly quadrant entire day except for an occasional swing into the east.
1640L: Took off for Kwajalein. Flew through a line of showers about 40 mi. south of Bikini. Within the line of showers (extending E to W) the sky coverage was about 6/10, base of clouds 1,500 ft, tops estimated 15,000 ft. No other types of clouds

29 July (con't)

except swelling CU. After 15 min.of showers the sky was clear remainder of flight to Kwajalein.

30 July

Still at Kwajalein. Weather as reported by observer at Bikini was normal.

31 July

Still at Kwajalein. Intertropical front passed through Kwajalein, headed north at 2030L with few light gusts and light rain. Ceiling 2,000 ft; tops estimated 20,000 ft. Weather at Bikini reported as normal "trade" weather.

1 August

Departed Kwajalein for Bikini at 1500L. Sky clear at Kwajalein and to a point two thirds of the way to Bikini. From that point on CU clouds began with bases 2,000 ft. and tops 5,000 ft. As the flight progressed toward Bikini the cloud tops increased gradually until they reached 18,000 ft. over Bikini with a sky coverage of 9/10. There were scattered rain showers in the vicinity of Bikini. North of Bikini the sky was clear. The intertropical that passed Kwajalein yesterday seemed to be immediately over Bikini at 1700L today; very mild in nature. Contact flight conditions prevailed during entire flight. Wind over the lagoon was south to southeast, with heavy swells entering the lagoon through Enyu Channel to the south. Unable to land at Bikini due to swells. Returned to Kwajalein.

2 August

Departed Kwajalein at 0640L, Sky enroute Bikini; 7/10 CU at 2,000 ft; tops 5,000 ft, occasionally 10,000 ft. with scattered showers. Arrived at Bikini at 1830L. Wind at Bikini settled back to east; very light. No swells within the lagoon. Sky from Bikini northward clear. By 1000L 3/10 CU at 2,000 ft; tops 6,000 ft. formed and lasted all day.

3 August

Normal day; scattered CU at 2,000 ft. increasing to broken with occasional light showers by 1930L.

4 August

Very heavy showers for 30 min. about 0300L. Day dawned clear. 5/10 CU at 2,000 ft. formed by 1000L. Several light showers during late afternoon and evening.

5 August

The day started clear; became broken CU at 2,000 ft. by 1100L and overcast with light rain and gusty wind by 1230L. The general set-up was suggestive of easterly wave activity.
1330L: The rain stopped and the clouds started to thin out. Situation normal with sky variable between scattered and broken at 2,000 ft. by 1500 L.

6 August

Usual nocturnal showers. At 0730L a dark line of clouds based at 1500 ft.

6 August (con't)

oriented north to south, approached from the east. Heavy rain fell from 0730L to 0830. Tops of CUs and CBs estimated 15,000 ft. Cloud bank moved off to the west by 0845L leaving scattered clouds at 2,000 ft. Clouds started to rebuild vertically and increased to broken with occasional heavy showers by 1130L and remained this way for the day.

7 August

No nocturnal showers. 5/10 CU at 2,000 ft. all day. Heavy showers started at 2100L with occasionally heavy gusts of wind until midnight.

8 August

The day started with the normal scattered CU at 2,000 ft. with no build-ups.
1700L: A line of CB, visible to the east was oriented north-south.
1800L: The line of CB east is approaching rapidly; tops estimated 20,000 ft.
1815L: Wind becoming gusty from ENE with CBs moving overhead rapidly at 2,000 ft. Patches of scud drifting rapidly at 500 ft. from the east. A few drops of rain fell. The clouds changed their orientation from N-S to NNE-SSW.
1830L: Now raining heavily. Ceiling 500 ft; visibility two miles.
1900L: Rain stopped. Line of clouds moving off to the west. A new line of CBs approaching from the east. Majority of CBs have ideal anvil tops with false CS blowing from the tops.
2130L: Occasional lightning to the SE. Frequent moderate showers fell remainder of evening.

9 August

Wind started to pick up with occasional strong gusts about 0300L.
0530L: Wind in peak gusts; easterly 45 kt. Intermittent, heavy rain.
0600L: Rain became continuous and very heavy. Wind changed to SE, 45 kt.
0730L: Rain changed to light and intermittent, remaining thus until 1030L.
1030L: The rain came in frequent moderate showers from this time until 1300L. 2½ in. of rain fell within the previous twelve hour period.
1300L: Conditions now improving very rapidly. Sky is 6/10 AC with 4/10 CU and CB. Occasional breaks in AC showed tops of CB to be an estimated 25,000 ft. Wind direction SE and subsided to 30 kt. Occasional very light showers remainder afternoon.
1900L: Ceiling lowered rapidly to 800 ft; visibility 1 mi. in heavy rain. Wind estimated 15 kt.
1940L: Conditions improving rapidly.
2300L: Determination of cloud types not possible. Coverage is about 4/10. Wind estimated 30 kt.
2359L: Sky overcast. Too dark to discern cloud types. Wind still estimated 30 kt.

10 August

0000L: Sky overcast, too dark to discern cloud types.
0630L: Sky 4/10 CU based at 2,000 ft; tops 5,000 ft. with occasional swelling CU up to 10,000 ft. This condition prevailed remainder of day with sky occasionally becoming broken and with occasional showers.

11 August

Scattered CU at 2,000 ft; tops 5,000 ft, occasionally 8,000 ft. with occasional showers.

12 August

Heavy rain started about 0100L this morning and became intermittent by 0200L. The rain changed to light and intermittent by sunrise and remained this way for the rest of day. Sky was overcast with average ceiling of 1,000 ft; visibility extremely variable from 1 to 10 mi. remainder of day. Rain ceased for 2 hr. at noon.

13 August

Scattered CU at 2,000 ft; tops 5,000 ft. entire day.

14 August

Few CU at 2,000 ft; occasionally clear; entire day.

15 August

Sky remained clear until noon today. High, thin overcast with low scattered CU at 2,000 ft. from noon until end of day.

16 August

High, broken, low scattered clouds at 2,000 ft. entire day. Wind calm most of day.

17 August

Wind changed from ENE, 7 kt at midnight, to ESE, 10 kt at noon. Scattered CU at 2,000 ft. entire day with occasional showers.

18 August

Nocturnal showers. 2/10 CS with variable 3/10 to 6/10 CU at 2,000 ft. were present the entire day. Occasional light showers.

19 August

3/10 CS with low clouds variable from less than 1/10 to 7/10 at 2,000 ft. were observed. Occasional build-ups to 15,000 ft. south of Bikini.

20 August

Heavy nocturnal showers about 0200L. Sky clear at sunrise. 3/10 CU at 2,000 ft; tops 8,000 ft. formed by 1130L along with one shower, after which the sky cleared again and remained thus remainder of day (except for CBs distant to the east through south to southwest). 3/10 CU formed at 2,000 ft. after sunset with occasional light showers from sunset until midnight.

21 August

Sky variable between 3/10 to 7/10 CU at 2,000 ft; tops 5,000 ft.

22 August

The day started with 6/10 CU at 2,000 ft; tops 5,000 ft. Occasional tops to 10,000 ft. over the western side of the lagoon lasted the entire day. Occasional light showers from 2100L until midnight. A layer of CS estimated at 20,000 ft. progressed across the sky from the east, starting at 1200L and becoming 10/10 by 1500L. This formation remained for the day. Normal trade winds.

23 August

Light nocturnal showers until daybreak. The day started with 4/10 CU at 2,000 ft. developing into swelling, towering CU with tops estimated 15,000 ft. by 1100L. After 1100L multiple layers of AS developed at various elevations from 8,000 to 16,000 ft. representing 5/10 sky cover. Distant rain showers all directions with an occasional shower over Bikini. This situation prevailed entire day.

24 August

The situation that prevailed yesterday continued today. By 1100L the towering CUs had become CBs with tops estimated 20,000 ft., with heavy showers in all directions. The wind was calm most of the day. At 1500L the wind increased to 25 kt from the SSE with an occasional sprinkle. By 1515L a large CB had moved directly overhead making the sky overcast with moderate rain. By 1630L the CB had moved off to the NW and the wind subsided to a dead calm. The sky remained a complete overcast remainder of day with a combination of very tall CBs and multiple layers of thick AS. Occasional light rain and calm winds prevailed remainder of day. The weather was typical of intertropical activity, although the intertropical is supposed to be still 100 mi. south of Bikini.

25 August

The day started with 9/10 AC-AS with 1/10 CU at 2,000 ft; tops 5,000 ft. Wind E to ENE; 15 kt, occasionally gusty to 28 kt. This condition prevailed entire day.

26 August

The day started with 9/10 AC-AS estimated at 14,000 ft. with 1/10 CU at 2,000 ft.; tops 6,000 ft. The high clouds dissipated to 5/10 by 1300L. The surface wind was E to ENE; 15 kt; occasionally gusty to 35 kt.
1500L: A line of AS and CS extending E-W is visible distant south. Looks like the tops of the intertropical front.
1530L: The line of high clouds south is much closer now with tops of CSs visible.
1600L: The line of clouds south is definitely of an intertropical nature.
Rapidly moving scud and rain squalls visible beneath CBs. Estimated distance of system is 15 mi. south. Estimated time of arrival over Bikini is 1700L.
1630L: The whole system is now moving in rapidly. The wind changed to south 25 to 35 kt.
1700L: The wind subsided. Ceiling is 800 ft. Visibility is 2 mi. with intermittent light rain.
1730L: Ceiling and visibility raised to 1,500 ft, and 5 mi. with still intermittent light rain. Wind mostly calm except for occasional light gusts preceding the beginning of rain.
2000L: Intermittent heavy rain with occasional heavy gusts from the SE from 2000L until the end of the day (midnight).

27 August

0000L: Intertropical weather continued same as above.
0200L: The rain became continuous and changed to light. Occasional thunder.
0700L: Rain stopped. Conditions improving rapidly. Wind calm. Sea glassy smooth.
0800L: Overcast layer of thick AS estimated 12,000 ft. with 2/10 CBs distant all quadrants.
0830L: Very dark CBs covering eastern horizon based 1,000 ft., tops penetrating the overcast AS. Occasional thunder distant east. Rain squalls NE to SE.
0945L: System of clouds just described is now overhead with moderate rain. Ceiling is 800 ft., visibility 2 mi. Wind easterly 10 kt for a few minutes then subsided to calm.
1015L: Rain became light and intermittent and the ceiling raised to 2,000 ft., visibility raised to 5 mi. Wind still calm.
1045L: Rain stopped.
1100L: Low clouds dissipating rapidly and the wind is beginning to blow from the east.
1200L: Overcast layer of thick AS at 12,000 ft. with a few SC and CU at 2,000 ft.
1600L: AS clouds have dissipated to 2/10 thin AS at 14,000 ft. and 4/10 CS at estimated 18,000 ft. No increase in low clouds. Visibility 15 mi. Surface wind returned to normal (ENE 15 kt).
2000L: Sky became clear except for few AS and few CU and remained thus until midnight.

NOTE: All times used in the above log are local and twelve hours should be subtracted to give GCT.

WEATHER DATA

SIX-HOURLY WEATHER OBSERVATIONS MADE AT BIKINI STARTING 15 JULY 1947.

(Time and Dates Based on GCT)
"55555" Ship Code

15 July

32116	65500	04501	13886	32163	10012	00307
32116	65506	03401	11889	35934	10013	00610
32116	65512	08401	13883	30000	10010	00110
32116	65518	08301	11883	31001	10011	00510

16 July

42116	65500	18301	13887	32304	10013	00110
42116	65506	08401	11893	31853	10081	00510
42116	65512	08401	13883	32013	10011	00110
42116	65518	08401	11884	31002	10011	00710

17 July

52116	65500	08401	13888	32813	10011	00110
52116	65506	08401	11893	31865	10012	00710
52116	65512	08865	14877	30009	10069	00315
52116	65518	06401	11878	36003	00063	00615

18 July

62116	65500	08401	13888	31945	00013	00110
62116	65506	08301	11892	31953	00012	00710
52116	65512	08361	14882	36105	00013	00315
62116	65518	08661	12880	39306	00028	00610

19 July

72116	65500	06501	14886	31995	00011	00110
72116	65506	06402	11887	32747	00013	11615
72116	65512	08501	14686	36003	00053	00115
72116	65518	04514	13680	30009	00069	00705

20 July

12116	65500	08401	14684	38894	00043	00105
12116	65506	08401	12885	32624	10013	00610
12116	65512	08401	14684	30602	10062	00110
12116	65518	08401	13683	30401	10011	00705

21 July

22116	65500	08401	14887	31004	10014	00205
22116	65506	08501	12889	32003	10013	00610
22116	65512	08501	14682	36002	10052	00110
22116	65518	08601	12682	30703	10083	00605

22 July

32116	65500	08661	14783	33208	10063	00205
32116	65506	10661	12783	36688	10083	00610
32116	65512	10614	15781	30009	10059	00315
32116	65518	12402	13780	36235	10083	00610

23 July

42116	65500	08401	15889	32464	10023	00210
42116	65506	06301	13894	31814	10003	00610
42116	65512	08301	15883	31403	10012	00210
42116	65518	08561	14782	37008	10018	00705

24 July

52116	65500	10302	16784	33907	10083	00310
52116	65506	08421	13787	39945	10054	00615
52116	65512	08401	15885	32804	10013	00110
52116	65518	08401	13883	32714	10013	00610

25 July

62116	65500	06501	14890	32314	10013	00105
62116	65506	08401	12892	32513	10002	00710
Missing						
Missing						

26 July

Missing
Missing
Missing
Missing

27 July

12116	65500	08401	18882	35493	10012	00110
12116	65506	08201	15885	3[illegible]795	10013	00615
12116	65512	Missing				
12116	65518	Missing				

28 July

22116	65500	10461	15886	38638	10084	00105
22116	65506	10361	14781	35708	10064	00705
Missing						
Missing						

29 July

32116	65500	12210	15887	38925	10013	00110
32116	65506	08201	14886	37665	10014	00605
Missing						
Missing						

30 July

42116	65500	08201	15889	31003	10013	00110
42116	65506	08210	14887	33043	10012	00705
Missing						
Missing						

31 July

52116	65500	08201	17887	32054	10063	00110
52116	65506	08210	14882	33966	10084	00615
Missing						
Missing						

1 August

62116	65500	14413	17782	33706	10065	00210
62116	65506	12110	15881	33855	10013	00610
Missing						
Missing						

2 August

72116	65500	08201	16888	32035	10084	00705
72116	65506	08301	13885	32003	10013	00615
Missing						
Missing						

3 August

12116	65500	10361	14781	37605	10084	00110
12116	65506	06201	12885	32394	10013	00610
12116	65512	00001	14780	32002	10082	00310
Missing						

4 August

22116	65500	08301	14890	32604	10063	00110
22116	65506	08301	13884	32895	10082	00705
22116	65512	08402	16782	33785	10083	00315
22116	65518	08302	13781	32074	10012	00615

5 August

32116	65500	16410	15886	35005	10015	00710
32116	65506	08301	13884	32794	10082	00610
Missing						
Missing						

6 August

42116	65500	08301	16836	33134	10083	00010
42116	65506	08301	13884	32033	10010	00605
42116	65512	08281	16780	39334	10013	00310
42116	65518	08401	14879	32003	10013	00705

7 August

52116	65500	06401	15887	32004	10084	00005
52116	65506	04410	12783	32734	10012	00605
52116	65512	04601	15681	32703	10082	00110
52116	65518	08501	12780	31703	10011	00610

8 August

62116	65500	08301	14883	31643	10012	00105
62116	65506	06201	12886	32814	10083	00610
62116	65512	08501	14778	36703	10062	00205
62116	65518	14963	11677	36708	10063	00610

9 August

72116	65500	14763	13677	30208	10068	00005
72116	65506	08401	12788	32307	10083	00605
72116	65512	12401	14680	30203	10083	00105
72116	65518	10301	12680	32703	10012	00605

10 August

12116	65500	06401	13887	32025	10013	00105
12116	65506	06401	10880	33795	10014	00805
12116	655	Missing				
Missing						

11 August

22116	65500	08410	12888	33095	10014	00105
22116	65506	10501	09885	31434	10012	00805
22116	65512	10453	12779	33203	10012	00110
Missing						

12 August

32116	65500	08310	12785	38608	10013	00005
32116	65506	10452	10679	39208	10064	00705
Missing						
Missing						

13 August

42116	65500	08402	12887	32865	10013	00100
42116	65506	06301	11885	32165	10012	00605
42116	65512	08301	13783	32203	10081	00110
42116	65518	06302	11682	36206	10092	00605

14 August

52116	65500	06401	12888	31003	10013	00105
52116	65506	06301	13885	31006	10013	00605
52116	65512	08501	13782	36002	10012	00107
52116	65518	08301	10781	32105	10013	00109

15 August

62116	65500	04402	11888	31715	10013	00003
62116	65506	06301	09886	31704	10012	00807
62116	65512	00025	13680	33207	10083	00107
Missing						

16 August

Missing						
72116	65506	00002	10885	32926	10033	00605
72116	65512	04201	13782	32003	10013	00207
Missing						

17 August

12116	65500	10301	12787	22004	10014	00104
12116	65506	08301	11885	32393	10012	00505
12116	65512	06201	14782	31002	10012	00310
12116	65518	08401	13780	38003	10013	00607

18 August

22116	65500	08301	14886	38006	10015	00104
22116	65506	08402	12884	38707	10014	00505
22116	65512	06401	14783	38003	10023	00305
Missing						

19 August

32116	65500	Missing				
32116	65506	06401	12885	31834	10013	00608
Missing						
Missing						

20 August

42116	65500	08401	14786	38013	10013	00204
42116	65506	08301	12885	31704	10013	00502
42116	65512	08200	14881	30000	10010	00101
42116	65518	Missing				

21 August

52116	65500	08202	13889	32046	10015	00002
52116	65506	04402	10884	32077	10023	00604
52116	65512	06301	13882	32103	10081	00104
52116	65518	06250	12679	32203	10082	00606

22 August

62116	65500	10302	13887	32766	10023	00004
62116	65506	06301	11885	32024	10013	00804
62116	65512	08401	13883	32013	10083	00102

23 August

72116	65500	12401	13886	32914	10083	00106
72116	65506	04402	11881	32607	10083	00601
72116	65512	08301	14882	31001	10011	00504

24 August

12116	65500	08302	13887	32645	10014	00002
12116	65506	12482	12780	32208	10022	00204
12116	65512	00002	14880	32705	10022	00205

25 August

22116	65500	08202	14882	32707	10021	00205
22116	65506	08202	11884	32707	10024	00504

26 August

32116	65500	08402	14887	38736	10013	00102
32116	65506	06481	12680	32207	10083	00503
32116	65512	08215	15780	36207	10062	00204

PIBALS TAKEN ON BIKINI ISLAND
(All GCT)

28 July

12116	65500	00925	0826	20830	0837	40730
0727	60824	0924	80922	0920	00825	20817

29 July

32116	65504	00925	0905	20905	0905	Lost in Sun.

30 July

42116	65501	00913	0916	20915	0911	Entered clouds.

31 July

PIRA

1 August

62116	65501	01519	1519	21814	1514	41510
1011	61015	1112	81108	1707	01210	1111
21117	1122	41128	51132	00830		

2 August

72116	65502	00623	0622	20621	0724	40726
0725	60823	0822	80925	0931	00928	0927
21033	1036	41034	50933	00927		

3 August

12116	65501	00816	0821	20822	0923	40920
0820	60820	0820	80820	0719	00619	0620
20720	0723	40727	50728			
12116	65520	00823	0830	21032	0934	41032
1031	61126	1125	81026	1125	01125	1220
21217						

4 August

22116	65502	00810	0813	20813	0913	40913
0912	60910	0810	80808	0807	00908	1011
21013	1012	40911	50910			
22116	65521	00610	0610	20711	0709	40706
0908	61207	1208	81309	1509	00905	1105
21007	1313	41115	50915	01017	51510	01409

5 August

32116	65521	01010	0912	20922	0921	40816
0720	60717	0714	80714	1015	00815	0616
20814	0712					

6 August

42116	65502	01015	1018	20920	0923	40822
0823	60823	0821	80818	0815	00817	0811
20808	0711	40711	50808	00620	50815	00824

No pibals for 7,8,9,10,11 August

12 August

32116	15501	00823	0925	20920	0920	41021
1020	60915	0714	80715	0920	01020	1021
21020						

13 August

42116	65502	00916	0822	20824	0924	40923
0820	60917	0916	80918	0918		

14 August

52116	65501	00719	0721	20823	0825	40825
0825	60820	0815				
52116	65519	00823	0724	20723	0823	40819
0911	60917					

15 August

62116	65520	01304	1308	21207	1105	41105
0908	60809					

16 August

No pibal

17 August

12116	65501	01110	1014	21018	1021	41020
1020	61018	1016				
12116	65520	00916	0922	20925	0927	40921
0920	60920	0919	81920	0919		

18 August

No pibal

19 August

32116	65501	00917	1020	20925	1032	41032
1021	61026	1028	81026			

20 August

42116	65501	01018	1126	21130	1127	41029
1029	61027					

21 August

52116	65501	00822	0822	20822	0925	40919
00916	60916	0917				

22 August

62116	65501	00916	0919	20926	0921	40919

22 August (con't)

1018	61016	1015	81016	1016		

No pibals for 23 or 24 August

25 August

22116	65501	00712	0812	2911	1014	41013
1014	60910	0811				